



CALIFORNIA ENERGY COMMISSION

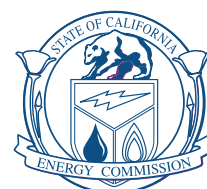
# PUBLIC INTEREST ENERGY RESEARCH

2003 ANNUAL REPORT

Appendix 7  
Energy Innovations Small Grant



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Arnold Schwarzenegger,  
*Governor*

## Energy Innovations Small Grant

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## **EISG Multi-Year Projects Started in 2003**

## **A Lox-NO<sub>x</sub> Porous Ceramics Burner Performance Study**

**EISG Grant Number:** 02-14

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Pei-feng Hsu (321) 674-7246

**Organization:** Florida Institute of Technology

**Grant Amount:** \$74,988

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of a multi-layer cylindrical shaped porous ceramic burner to achieve stable combustion. The emissions and heat release performance of the new porous ceramics burner will be examined in a laboratory environment. Economic analysis of the operation and related cost will be conducted and compared with the existing low NO<sub>x</sub> burners, for example, the radiant surface burners made with ceramic fiber mats. It is expected that this study will provide valuable information about the design and operation of porous radiant burners and lead the way to prototype development and demonstration in a future effort.

### **Proposed Outcome:**

- A porous ceramic burner will be fabricated with R-type thermocouples embedded at the interfaces of different porosity ceramics. A radiance measurement system will be constructed.

### **Anticipated Benefit:**

- Potential to increase the efficiency and reduce the NO<sub>x</sub> emissions from boilers used for power generation in California.

### **Project Status:**

- Construction of bench-top burner and calibration - 40%.
- Construction of radiance measurement system – 0%.
- Measurement of burner emissions – 0%.
- Measurement of radiant heat flux output – 0%.
- Economic analysis – 0%.

**A Novel Integrated Doubly-Fed Electric Alternator/Active Filter (IDEA) for Wind Power Applications**

**EISG Grant Number:** 02-27

**PIER Area:** Renewables

**Principal Investigator:** Hamid Toliyat (979) 862-3032

**Organization:** Texas A&M University

**Grant Amount:** \$75,000

**Status:** Active

**Project Description:**

The purpose of this project is to determine the feasibility of integrating a low cost active filter for power factor correction into the power electronics that control Doubly Fed Electric Alternators used on state of the art variable speed wind turbines.

The proposed technology will be tested on a 7.5 hp laboratory modeled wind turbine equipped with the proposed IDEA. The advantages of the proposed approach are:

- Adjustable speed control of wind turbine in order to capture maximum wind energy.
- Compensation of the harmonics in the grid and maintaining the total harmonic distortion (THD) of the grid within the acceptable rang according to IEEE 519 standard.
- Improving the power factor and reactive power control and totally improving power quality.
- The approach is rugged and can be adapted to low and medium voltage systems.
- The system can be controlled to simultaneously generate active green power, compensate for the reactive power and harmonics generated by the nonlinear loads in an industrial, agricultural, and water plant.

**Proposed Outcome:**

- A prototype system will be fabricated and tested as part of the project.

**Anticipated Benefits:**

- Potential to reduce the life cycle cost of power generated from adjustable speed wind turbine systems by improving the power quality output from double fed induction generators which provide the lowest cost power electronics solution.
- Potential to improve the grid power quality in locations that have grid tied wind turbines.

**Project Status:**

- Projected start date September 15, 2003.
- First progress report due no later than 4 months after start date.

**Application of Stochastic Filtering and Control Methodology to the Optimization of Wind Turbine Control Design**

**EISG Grant Number:** 03-01

**PIER Area:** Renewables

**Principal Investigator:** A. V. Balakrishnan (310) 825-1594

**Organization:** University of California, Los Angeles

**Grant Amount:** \$74,993

**Status:** Pending

**Project Description:**

The purpose of this project is to demonstrate the feasibility of applying stochastic filtering and control theories to the problem of improving energy production and mitigating transient fatigue loads for large-scale wind turbines.

**Proposed Outcome:**

- A comprehensive nonlinear dynamical system model for large-scale wind turbines will be developed and tested as part of the project.

**Anticipated Benefits:**

- Potential to reduce the cost of energy for wind-generated electricity by 3-5%.
- The proposed advanced optimal control algorithms have the potential to increase the power captured and prolong the lifetime of wind turbines.

**Project Status:**

- Projected start date January 1, 2004.
- First progress report due no later than 4 months after start date.

## **Build and Test a 3 kW Prototype of a Co-Axial, Multi-Rotor Wind Turbine**

**EISG Grant Number:** 02-18

**PIER Area:** Renewables

**Principal Investigator:** Douglas Spriggs Selsam (714) 992-5594

**Organization:** Selsam Innovations

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to determine the feasibility of a low cost wind turbine design that incorporates 7 rotors on a horizontal shaft. A 3 kW prototype will be fabricated and tested as part of the project. The new design, now proven in small models, combines the power of multiple smaller rotors mounted to a single elongate driveshaft, to give the same power as a single larger rotor, with less cost, weight, and complexity. This research will pave the way for more advanced turbines utilizing this new co-axial, multi-rotor technology.

### **Proposed Outcomes:**

- A 3 kW prototype will be constructed and tested.

### **Anticipated Benefits:**

- Potential to reduce the footprint of wind turbines while maintaining the same power output which would allow wind farms to increase there electrical output cost effectively.
- Potential to reduce the cost of wind turbine power be using lower cost rotors that are less costly to buy and maintain.

### **Project Status:**

- Build a 3 kilowatt multi-rotor, co-axial turbine – 70%.
- Preliminary testing – 50%.
- Revise prototype for long term testing – 20%.
- Perform long term (6 months) testing – 0%.

## **Carbon Catalyzed Natural Gas Processing**

**EISG Grant Number:** 02-21

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Steve Chu (612) 877-0765

**Organization:** Sunnyside Technologies, Inc.

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to determine the feasibility of producing both carbon monoxide (CO)-free hydrogen for PEM fuel cells and nanostructured carbon for carbon fuel cells through a precisely controlled chemical processing of natural gas catalyzed by nanostructured carbon resulting in four times the H<sub>2</sub> yield of conventional thermal cracking process. This technology eliminates the complex CO removal processes in conventional hydrogen production such as steam reforming and gas shift reaction. Therefore it will increase the hydrogen quality, reduce the production cost, and be more competitive.

### **Proposed Outcome:**

- To correlate the relationship among the process parameters, carbon structures, catalytic activities, and the electrochemical performance as fuel.

### **Anticipated Benefits:**

- Potential to provide high quality hydrogen fuel and carbon fuel from natural gas without the production of the greenhouse gas CO<sub>2</sub>.
- Potential to provide the correct type of carbon fuel for carbon fuel cells, which are capable of energy efficiencies up to 80%.

### **Project Status:**

- Projected start date August 1, 2003.
- First progress report due no later than 4 months after start date.

## Construction and Testing of a High-Efficiency Solar Water Still

**EISG Grant Number:** 03-07

**PIER Area:** Industrial/ Ag/ Water

**Principal Investigator:** Paul LaViolette (703) 256-4887

**Organization:** The Starburst Foundation

**Grant Amount:** \$74,998

**Status:** Pending

### Project Description:

The purpose of this project is to determine the feasibility of developing a novel multi-effect solar still design that is capable of cost effectively desalinating agricultural drainage water for reuse in crop irrigation.

### Proposed Outcome:

- A prototype will be fabricated and tested as part of the project.

### Anticipated Benefits:

- Potential to provide significant power savings since the proposed technology consumes only about 500-kilowatt hours per acre-foot of processed water, which is about 7 times less power than reverse osmosis.
- Potential to desalinate drainage water with up to 10,000 total dissolved solids at a cost of \$490/AF, which is comparable to reverse osmosis, but with considerably less power consumption and waste brine volume.

### Project Status:

- Projected start date January 1, 2004.
- First progress report due no later than 4 months after start date.

**Demonstration of Energy Efficient Enhancement in Refrigeration Appliances by Incorporation of Practical, Low Cost Thermal Energy Storage**

**EISG Grant Number:** 02-24

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Timothy James (805) 252-7190

**Organization:** TES Technology, Inc.

**Grant Amount:** \$75,000

**Status:** Active

**Project Description:**

The purpose of this project is to demonstrate the feasibility of using a novel thermal energy storage design to increase the energy efficiency of refrigeration and cooling appliances. Target refrigeration appliances include domestic appliances (combination or stand alone refrigerators and freezers), notoriously inefficient compact refrigerators (found in hotel rooms, dorm rooms, home bars, etc and now being mass marketed by major retail chains.) commercial vending and display cases, domestic and small commercial air conditioning etc. Thermal energy storage (TES), when appropriately incorporated into refrigeration appliances, improves energy efficiency by stabilizing the evaporation temperature and eliminating the inefficient low temperature excursions typical of on-off modulated vapor-compression refrigeration systems. Additional efficiency and other benefits include a narrower operating temperature range and more stable storage temperatures and humidity levels. For vending and display cases TES can provide reserve capacity for peak cooling loads (e.g., chilling new warm product) thus eliminating the need for a high capacity cooling system with compromised efficiency under steady-state conditions. For small capacity a/c TES can provide stored capacity enabling peak load shifting and interruptible or off-peak power utilization.

**Proposed Outcome:**

- A prototype system will be fabricated and tested in two refrigerator models.

**Anticipated Benefits:**

- Potential to reduce residential energy consumption by 95 kWh/year (assumes conventional refrigerators consume 475 kWh/yr and 20% efficiency improvement).
- Potential to save up to 160 gWh/year statewide in just residential refrigerators (assumes 16 million units in CA, 475 kWh/yr/unit, 10% market penetration, 20% energy savings).

**Project Status:**

- Measure energy consumption and temperatures versus time – 50%.
- Perform sensitivity analysis on key design parameters – 0%.
- Design and Build tooling and fabricate TES – 0%.
- Develop test plan and deliver to EISG program administrator for approval – 100%.
- Measure Energy Consumption – 0%.
- Evaluate variations – 0%.



## **Detecting Optimal Fan Pressure**

**EISG Grant Number:** 02-03

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Clifford Federspiel (510) 418-3392

**Organization:** Federspiel Controls

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of using a new algorithm for more accurately determining the optimal pressure at which to operate variable air volume (VAV) air-handling systems. This project will involve the testing and demonstration of a new method of detecting the optimal pressure at which to operate variable air volume (VAV) air-handling systems. The ability to detect this pressure will enable VAV system use less energy during both on-peak and off-peak periods.

### **Proposed Outcome:**

- A test stand will be fabricated. The test stand will include a computer-based data acquisition system, a supply airflow station and a supply duct pressure sensor.

### **Anticipated Benefits:**

- The proposed algorithm has the potential to enable a reduction in source energy consumption in California of .018 quads. The reduction corresponds to an annual cost savings of \$171 million and a reduction in carbon emission of 0.27 million metric tons per year.
- Potential to reduce electrical consumption during peak electrical demand periods.

### **Project Status:**

- Fabricate Test Stand – 100%.
- Perform Experimental Testing – 100%.
- Analyze Test Results – 70%.

## **Development of a Modular Scroll-Turbine-Based Organic-Ranking Cycle (ORC)**

**EISG Grant Number:** 03-06

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Malick Kane (510) 486-7380

**Organization:** EnefTech Corporation

**Grant Amount:** \$75,000

**Status:** Pending

### **Project Description:**

The purpose of this project is to determine the feasibility of developing a 5kW micro-power generation system based on the organic-Rankine cycle that incorporates a two-stage scroll turbine to reduce cost.

### **Proposed Outcome:**

- A prototype system will be fabricated and tested as part of the project.

### **Anticipated Benefits:**

- The proposed technology could help to satisfy the need for small distributed power generation systems that can operate on a variety of renewable heat sources (solar, biomass combustion, landfill gas etc.) to include waste heat.
- Potential to produce electricity at less than 5 cents/kWh, which is competitive with other generation technologies.

### **Project Status:**

- Projected start date January 1, 2004.
- First progress report due no later than 4 months after start date.

## **Development of Low Cost High Efficiency Heterojunction Organic Solar Cell Using Inkjet and Screen Printing Techniques**

**EISG Grant Number:** 03-04

**PIER Area:** Renewables

**Principal Investigator:** Ghassan Jabbour (520) 626-8324

**Organization:** University of Arizona

**Grant Amount:** \$75,000

**Status:** Pending

### **Project Description:**

The purpose of this project is to determine the feasibility of using the combination of inkjet and screen-printing technologies to fabricate low cost organic solar cells.

### **Proposed Outcome:**

- An all printed organic solar cell having efficiency greater than 4% will be fabricated and tested as part of the project.

### **Anticipated Benefits:**

- Addresses the need for low cost, flexible thin film solar cells with higher efficiency that would open up additional market applications for PV power generation.
- Potential to reduce the cost per kWh from organ solar cell systems by using low cost fabrication technologies.

### **Project Status:**

- Projected start date January 1, 2004.
- First progress report due no later than 4 months after start date.

**Development of Magnesium Diboride-Based Superconductor/Metal Matrix Composite Wire for use in Superconducting Transformers**

**EISG Grant Number:** 03-03

**PIER Area:** Energy Systems Integration

**Principal Investigator:** Matthew Holcomb (310) 567-6397

**Organization:** Nove Technologies

**Grant Amount:** \$72,060

**Status:** Pending

**Project Description:**

The purpose of this project is to determine the feasibility of developing a robust high-current Magnesium Diboride-based Superconductor/Metal Matrix Composite wire and tape for use in superconducting transformers operating at temperature in excess of 20K.

**Proposed Outcome:**

- Short and long (>10m) sections of wire will be developed and tested as part of the project.

**Anticipated Benefits:**

- Potential to reduce grid transformer losses by 40%.
- Potential to save 3,400GWh/year (valued at \$27 million at 8 cents per kWh) by 2010 given a 10% market penetration.
- The proposed technology could reduce load loss by nearly a factor of two by the direct replacement of small to medium power range (10-100MVA) conventional transformers with superconducting transformers operating at 25K.

**Project Status:**

- Projected start date January 1, 2004.
- First progress report due no later than 4 months after start date.

## **Development of Universal Software for Dissolved Oxygen Control in the Activated Sludge Process**

**EISG Grant Number:** 02-22

**PIER Area:** Industrial/ Ag/ Water

**Principal Investigator:** Alex Ekster (510) 657-7066

**Organization:** Ekster & Associates

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to determine the feasibility of developing control software capable of reliably regulating dissolved oxygen levels in the activated sludge process in wastewater treatment plants by quickly detecting hardware malfunctions that impact dissolved oxygen (D.O.) levels. Upon successful testing and updating the algorithms, they will be computer coded, and prototype of D.O. control software will be tested at the 32 million gallon a day wastewater treatment plant located in Oxnard, Ca.

### **Proposed Outcome:**

- Prototype control software will be developed and field-tested in a wastewater treatment plant.

### **Anticipated Benefits:**

- Potential to reduce California energy consumption at wastewater treatment plants by 5-10%. If you assume only a 5% reduction in energy in 80 large treatment plants the energy savings would be approximately 49 gWh/year. There are about 800 treatment plants in California.
- Potential to reduce the number of accidental releases of improperly treated wastewater from treatment plants that seek to save energy by optimizing dissolved oxygen levels.

### **Project Status:**

- Develop computer models of D.O. control system faults for use in testing the fault detection algorithms – 100%.
- Develop computer model that incorporates the activated sludge process and aeration system for use in testing the D.O. control algorithms – 5%.
- Assemble a hardware/software prototype system with operator interface – 0%.
- Test control algorithm at the 32 MGD wastewater treatment plant – 0%.

## **Dry Steam Scrubbing for Impurity Removal from Geothermal Steam**

**EISG Grant Number:** 02-13

**PIER Area:** Renewables

**Principal Investigator:** Paul Hirtz (707) 575-1310

**Organization:** Thermochem, Inc.

**Grant Amount:** \$74,940

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of developing a steam scrubbing technology that effectively removes and/or treats corrosive hydrogen chloride (HCl) in geothermal steam without superheat quenching or steam condensation so that the maximum amount of mass and energy can be retained for power generation. This pilot-plant study will test a hybrid calcite bed and amine treatment Dry Steam Scrubbing (DSS) process and provide the information needed to determine if the process is technically and economically feasible for full-scale implementation.

### **Proposed Outcome:**

- An existing pilot-plant facility for use in testing will be upgraded. This will involve design of bed configurations, a new containment vessel, water-wash regeneration system, corrosion monitoring system, plus fabrication and installation of new equipment. An optimized calcite bed configuration will be developed.

### **Anticipated Benefits:**

- Potential to produce total heat savings of 40 Btu/lb steam, equal to 4.7 MW of gross heat energy or about 1.5 MW electrical power for a 20 MW plant.
- Potential to provide a 3% to 5% improvement in geothermal generation efficiency.

### **Project Status:**

- Engineering design for pilot plant upgrades – 75%.
- Fabricate equipment for pilot plant upgrades – 50%.
- Install equipment for pilot plant upgrades – 50%.
- Start-up and operate pilot plant facility – 25%.
- Evaluate initial data, design optimum bed configuration – 0%.

## Emission Monitoring of Nitric Oxide with a Mid-IR Solid State Laser

**EISG Grant Number:** 02-20

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Robert Cattolica (858) 534-2433

**Organization:** University of California, San Diego

**Grant Amount:** \$75,000

**Status:** Active

### Project Description:

The purpose of this project is to determine the detection limits for nitric oxide at combustion exhaust conditions using mid-infrared solid-state laser. The ultimate goal of this research is to determine the feasibility of replacing traditional nitric oxide emission monitoring with a chemiluminescence analyzer (technology that is more than 40 years old) with new solid-state laser technology. This new laser technology, in addition to the potential for improved detection limits, can be multiplexed to provide measurements at multiple locations and by using other wavelengths access other species of interest: NO<sub>2</sub>, CO, CO<sub>2</sub>, NH<sub>3</sub>, etc.

### Proposed Outcome:

- An operational one-meter long combustion exhaust simulator will be constructed. A prototype mid-IR laser will be fabricated and tested in the combustion exhaust simulator.

### Anticipated Benefits:

- In the near future, the mandated NO<sub>x</sub> emission levels for gas turbines used for power generation will be so low that current NO<sub>x</sub> measurement technologies will not be able to measure the emission levels accurately. This proposed technology has the potential to provide measurement accuracy sufficient to measure mandated levels well into the future.
- If successful, the proposed technology has the potential to accurately measure low levels of a wide variety of emission species further facilitating the setting and verification of various harmful emissions.

### Project Status:

- Design of hardware and order material – 25%.
- Design and order gas control and temp. monitoring – 25%.
- Develop software to operate combustion simulator – 25%.
- Model IR Absorption Spectra of Nitric Oxide – 25%.
- Design integration of exhaust simulator with PSI, Inc. – 100%.

## **End-Use Efficient, Environmentally Friendly Water Softening Device**

**EISG Grant Number:** 03-05

**PIER Area:** Industrial/ Ag/ Water

**Principal Investigator:** Nissen A. Jaffe (650) 961-1341

**Organization:** Material Methods, LLC

**Grant Amount:** \$74,996

**Status:** Pending

### **Project Description:**

The purpose of this project is to determine the feasibility of using an advanced Flow Through Capacitor in conjunction with new Ionic Charge Barriers to effectively soften tap water with low energy consumption.

### **Proposed Outcome:**

- Flow Through Capacitor prototypes will be fabricated and tested as part of the project.

### **Anticipated Benefits:**

- Potential to more effectively remove salts and other common contaminants, such as arsenic, perchlorate, permanganate, chromium, as well as other water soluble heavy metal ions.
- Potential to reduce wastewater generation by 80% over RO systems.
- Potential to reduce California energy consumption at wastewater treatment plants.
- Potential to operate at 60% of the energy usage compared to current state-of-the-art technology like RO.

### **Project Status:**

- Projected start date January 1, 2004.
- First progress report due no later than 4 months after start date.



## **Fault Location Techniques for Distributing Feeders Containing Distributed Generation**

**EISG Grant Number:** 02-04

**PIER Area:** Energy Systems Integration

**Principal Investigator:** Adly Girgis (864) 656-5936

**Organization:** Clemson University

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to demonstrate the feasibility of a computational strategy for determining the fault location in a transmission network containing distributed generation resources. The proposed strategy will be based on an analysis of the voltage and current waveforms on the three phase lines at various points in the distribution network.

Introducing distributed generation changes the power flow in distribution systems from a traditionally unidirectional to multi-directional power flow. Thus, there is a need to develop a new method for fault location. Locating faults in a distribution feeder is essential to speed the restoration of service and minimize the outage time of the distribution feeder. The proposed method considers the following factors:

- 1) The distribution feeder may contain single phase loads, two phase loads and three phase loads so system unbalance should be considered.
- 2) The feeder may include any number of distributed generators of different types along the feeder.
- 3) Data at the distributed generators may or may not be communicated to the substation computer.

The new fault location method to be developed will be based on the three phase components of the transmission line. The method can be used for balanced or unbalanced systems and will be based on the phasor quantities of the voltage and current waveforms at the substation.

### **Proposed Outcome:**

- Two algorithms will be developed and utilized. First, an algorithm for calculating the voltage and current phasor quantities needed for the fault location algorithm using three-phase fault analysis will be developed. Second, a signal-processing algorithm, such as DFT and Kalman filtering, will be developed in order to obtain the phasor quantities when the voltage and current waveforms are obtained from EMTDC software simulations.

### **Anticipated Benefit:**

- Potential to provide California utilities with the ability to incorporate Distributed Generation (DG) into their distribution systems while maintaining the current level of system reliability.

**Project Status:**

- Determine the effect of distributed generation on calculating fault location – 100%.
- Develop component fault location method that accounts for distributed generation sources – 95%.
- Test three-phase fault location method – 90%.
- Obtain actual distribution feeder data with distributed generation – 100 %.
- Obtain actual distribution feeder data with distributed generation – 90%.

## Feasibility of a Hydrogen Blower Design for Fuel Cell Recirculation Applications

**EISG Grant Number:** 02-19

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** J. Patrick Sterchi (760) 788-7699

**Organization:** H2Systems, Inc.

**Grant Amount:** \$75,000

**Status:** Active

### Project Description:

The purpose of this project is to demonstrate the feasibility of using a unique blower design for recirculation of anode tail-gas in a hydrogen-fueled fuel cell system application. The net result of effective recirculation in a hydrogen fuel cell is a reduction in the amount of platinum catalyst that must be used in production. Since platinum is very expensive, this results in significant savings in the cost of each fuel cell unit. A fuel cell with proper recirculation could cut material costs by as much as 30%. This would result in estimated savings of \$0.003/kWh over the life of the power plant.

### Proposed Outcome:

- A 7cm blower prototype will be constructed. Blower performance curved based on experimental data will be produced showing flow rate, pressure rise, and power consumption for several operating points.

### Anticipated Benefits:

- Potential to produce a system with a low volume production cost of each unit to be in the \$250 to \$300 range.
- Potential to produce a hydrogen blower design that will meet the recirculation needs of a 1-10kW fuel cell power plant.
- Potential to provide a 25% - 30% direct savings on the fuel cell material platinum catalyst that must be used in production. Since platinum is very expensive, this may result in significant savings in the cost of each fuel cell unit.

### Project Status:

- Construct prototype hydrogen blower – 100%.
- Design and construct experimental test stand – 80%.
- Develop experimental test plan and deliver to the Program Administrator for approval – 100%.
- Conduct experimental research – 10%.

## **Flywheel System for Bulk Energy Storage**

**EISG Grant Number:** 03-02

**PIER Area:** Energy Systems Integration

**Principal Investigator:** Christopher Gabrys (775) 853-4651

**Organization:** Cobalt Energy

**Grant Amount:** \$75,000

**Status:** Pending

### **Project Description:**

The purpose of this project is to research the feasibility of using a new technology flywheel system concept for providing low cost bulk energy storage that can improve the reliability and dispatch-ability of renewable electricity generation.

### **Proposed Outcome:**

- A subscale flywheel system will be fabricated and tested as part of the project.

### **Anticipated Benefits:**

- Potential to provide energy storage at a cost of \$2/Wh capacity by increasing cycle life to 100,000 and achieving 95% efficiency.
- Potential to reduce the cost of energy storage by 80% over storage batteries.

### **Project Status:**

- Projected start date January 1, 2004.
- First progress report due no later than 4 months after start date.

## **Geothermal Reclaimed Water Turbine**

**EISG Grant Number:** 02-15

**PIER Area:** Renewables

**Principal Investigator:** Doug Jung (707) 523-4585

**Organization:** Two-Phase Engineering and Research

**Grant Amount:** \$75,000

**Status:** Pending

### **Project Description:**

The purpose of this project is to research the feasibility of installing down-hole turbines into geothermal injection wells at the Geysers.

### **Proposed Outcome:**

- A prototype down-hole turbine will be installed and tested.

### **Anticipated Benefits:**

- Potential to capture at least 25 MWe of electrical power generation currently available as a byproduct of environmental wastewater disposal.
- Potential to provide a system to acquire this energy that could be paid off in 2 to 3 years at \$20 per megawatt hour.

### **Project Status:**

- Projected start date January 1, 2004.
- First progress report due no later than 4 months after start date.

## High Efficiency Organic Thin Film Solar Cell

**EISG Grant Number:** 02-06

**PIER Area:** Renewables

**Principal Investigator:** Shalini Menezes (805) 497-2677

**Organization:** InterPhases Research

**Grant Amount:** \$75,000

**Status:** Active

### Project Description:

The purpose of this project is to demonstrate the feasibility of a low cost organic thin film solar cell device that can be fabricated using a simple robust process for organic/polymeric materials. Barriers to the widespread use of solar cells (photovoltaics) are mainly cost-related. Organic solar cells have many practical advantages ensuring their low cost production and product competitiveness. They include:

- Simple, non-toxic and inexpensive materials.
- Lightweight and flexible plastic substrate.
- Amenability to state-of-the-art, robust processing technologies such as coating and continuous roll-to-roll production.
- Large area and high volume production.

Lightweight, flexible organic solar cells will find applications in portable electronic devices, portable electricity systems, electric vehicles, space systems and building integrated PV, among others. Organic solar cells can also be transparent or mono-colored and thus can be used in see-through applications such as windows and sunroofs.

### Proposed Outcome:

- A solar cell will be constructed based on the proposed concept.

### Anticipated Benefits:

- Proposed technology has the potential to increase the conversion efficiency of organic thin film solar cells to at least 5% while keeping cost low.
- Proposed technology has the potential to provide low cost, high volume production of flexible thin film solar cells from inexpensive, easily processed organic and polymeric materials.

### Project Status:

- Build Scale Model – 50%.
- Install Flow Measure Instruments – 70%.
- Build and Install Flow Improvement Devices – 20%.
- Obtain Flow/Pressure Measurements – 0%.

## Hydrogen- Methane Waste Fermentations for Clean Electricity Generation

**EISG Grant Number:** 02-09

**PIER Area:** Renewables

**Principal Investigator:** John Benemann (925) 939-5864

**Organization:** Benemann Associates

**Grant Amount:** \$75,000

**Status:** Active

### Project Description:

The purpose of this project is to demonstrate a two-stage process for the anaerobic digestion (bacterial fermentation) of wastes to produce a mixed hydrogen – methane fuel, known to result in clean electricity generation, in particular low NO<sub>x</sub> emissions. The hydrogen fuel will be produced in the first stage and methane in the second, with the process yielding a desirable ratio of H<sub>2</sub> to CH<sub>4</sub> ranging from about 0.3:1 to 1:1 H<sub>2</sub>:CH<sub>4</sub> on a volume basis. Practical applications of this process will expand the potential applications of anaerobic digestion (AD) of wastes at a minimal incremental cost over conventional processes. The effect will be to reduce air pollution and allow additional electricity production in California non-attainment areas.

### Proposed Outcome:

- Bench-scale bioreactors using simulated and actual food and food processing wastes will be utilized. A technical and economic feasibility analysis will be carried out based on the experimental results.

### Anticipated Benefits:

- Potential to capture at least 25 MWe of electrical power generation currently available as a byproduct of environmental wastewater disposal.
- Potential to provide a system to acquire this energy that could be paid off in 2 to 3 years at \$20 per megawatt hour.

### Project Status:

- Project Start-up – 75%.
- Initial Experimental Work, System Testing – 0%.
- Mesophilic Operations with Simulated Food Wastes – 0%.
- Thermophilic Operations with Simulated Food Wastes – 0%.
- Operations with Simulated Food Processing Wastes – 0%.

## **Industrial Energy Recycling Process and Products**

**EISG Grant Number:** 03-09

**PIER Area:** Industrial/ Ag/ Water

**Principal Investigator:** Rick West (805) 543-4520

**Organization:** Distributed Power Technologies, LLC

**Grant Amount:** \$74,970

**Status:** Pending

### **Project Description:**

The purpose of this project is to determine the feasibility of developing an inverter with a user-friendly interface that can be used by power supply manufacturers to recycle the electrical energy used to test new power supplies as part of the manufacturing process.

### **Proposed Outcome:**

- Two 48Vdc, 200 watt, single phase prototype power recycling units will be fabricated and tested as part of the project.

### **Anticipated Benefits:**

- Potential to reduce the power consumption used for power supply burn in by a minimum of 91%.
- Potential to provide an 86% reduction in heat generation over conventional burn in testing.

### **Project Status:**

- Projected start date January 1, 2004.
- First progress report due no later than 4 months after start date.



## **Instant Snap-in Load Shed Device for Incandescent Lighting**

**EISG Grant Number:** 02-10

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Andrew Bierman (518) 687-7100

**Organization:** Rensselaer Polytechnic Institute

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to develop and test the electronic components necessary to receive the load-shed signal and dim an incandescent lamp accordingly. Once these components are developed, they will be tested under electrical and thermal conditions typically found in an incandescent lamp socket. A laboratory prototype of the snap-in incandescent load-shed device will be developed and tested under a variety of load-shed conditions.

### **Proposed Outcome:**

- A laboratory prototype of the snap-in socket adaptor device will be fabricated. An electrical and control component necessary to receive a power-line signal and dim incandescent lamps to a preset level on demand will be developed.

### **Anticipated Benefit:**

- Potential to provide a device that would allow building owners or utilities to reduce lighting load demand by between 30 and 50% instantly without adversely affecting the operation of electrical equipment or the ability of people to work with adequate lighting.

### **Project Status:**

- Projected start date October 1, 2003.
- First progress report due no later than 4 months after start date.

## **Integrating Evaporative Cooling with Dynamic Insulation for Occupant Thermal Comfort**

**EISG Grant Number:** 02-12

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Diane Griffiths (203) 857-0200

**Organization:** Steven Winter Associates, Inc.

**Grant Amount:** \$74,913

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of reducing peak cooling loads and increasing design day comfort in evaporatively cooled residences through the construction of a dynamic building envelope that uses exfiltrating air to reduce exterior wall and ceiling conduction loads and lower interior surface temperatures. The primary tasks proposed for this project include the construction and bench testing of dynamic ceiling and wall systems in order to determine the airflow that must be directed through these assemblies in order to completely offset energy gains. In addition to thermal performance, other issues to be examined will include ease of construction, building code compliance, first cost and aesthetics. Energy modeling using DOE-2 software will also be conducted in order to assess the thermal comfort on design days that would result from integrating an evaporative cooling system with dynamic insulation.

### **Proposed Outcome:**

- A testing apparatus capable of simulating the performance of the proposed dynamic ceiling and wall designs will be fabricated (dynamic ceiling and wall test panels). A DOE-2 analysis will be conducted.

### **Anticipated Benefits:**

- Potential to reduce peak cooling loads by up to 12%.
- Potential to provide a one degree Fahrenheit design day reduction in ceiling and exterior wall surface temperature, therefore improving occupant thermal comfort.

### **Project Status:**

- Bench test design and protocol development – 100%.
- Bench test construction and testing – 25%.
- DOE-2 Analyses – 0%.
- Preliminary design guidelines – 0%.

## Low Cost, Energy Saving Motor Controller for Residential and Industrial Buildings

**EISG Grant Number:** 02-02

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Patrick Chapman (217) 333-4694

**Organization:** University of Illinois, Urbana

**Grant Amount:** \$69,482

**Status:** Active

### Project Description:

The purpose of this project is to demonstrate the feasibility of integrating a unique motor drive with a specially designed 3-phase motor that allows the motor to be driven with single-phase power and will vary the speed of the motor to follow the load. Small electric motors collectively waste an enormous amount of energy on a worldwide scale. Many of these small motors are single-phase induction machines for appliances, heating, and air conditioning. However, a single phase motors are generally understood to have base performance worse than three phase motors. With existing electric power distribution, the single-phase machine is more convenient to use than its three-phase counterpart. By matching the speed to the load, the machine can be made to operate at its maximum efficiency operating point. Therefore, it is desirable to have a three-phase motor that can be driven from single-phase power.

### Proposed Outcome:

- A 500 W prototype will be fabricated and tested.

### Anticipated Benefits:

- Potential to demonstrate greater than 70% motor efficiency over a 10:1 speed range.
- Potential to achieve a unit cost of less than \$40.
- Potential to save California homeowners up to 25% on their AC energy consumption.

### Project Status:

- Design Integrated Motor and Drive System – 100 %.
- Build 500 W Slotless Induction Motor – 50 %.
- Build 500 W Electronic Drive – 100 %.
- Perform Online Tests – 95 %.
- Estimate Cost of Proposed System – 100 %.

## **Methane Sensor for Control and Automation**

**EISG Grant Number:** 02-08

**PIER Area:** Energy Systems Integration

**Principal Investigator:** Mourad Baraket (212) 217-2222

**Organization:** Carthago International Solutions, Inc.

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to introduce a new infrared sensor technology for the detection and measurement of methane (CH<sub>4</sub>) to control and automate the collection of biogas and the operation of distributed power generators (e.g. microturbines and fuel cells). The implementation of this technology in landfills will improve landfill-gas-to-electricity (LFGTE) conversion efficiency, enhance system reliability and lower operation and maintenance costs, thereby increasing the value, cost competitiveness of LFGTE systems.

### **Proposed Outcomes:**

- Fabricate a bench-scale sensor prototype for extensive tests to determine the sensor performance.
- Demonstrate the following operating parameters:
  - a) The CH<sub>4</sub> concentration range of 10-80 volume % will be determined.
  - b) Lowest detection: 5% volume-% of CH<sub>4</sub> in air.
  - c) Measurement accuracy: 2% full scale.

### **Anticipated Benefits:**

- Potential to increase the conversion efficiency of power generators at an estimated rate of 10 to 15%.
- Potential to provide a safe and reliable way of collecting biogas for green power generation.

### **Project Status:**

- Prototype Target Specification – 100%.
- Selection of sensor components –100%.
- Design sensor cell and housing –100%.
- Design of Circuit boards – 100%.
- Development of sensor software – 90%.
- Manufacturing of prototypes – 100%.
- Integration into test equipment – 100%.
- Preliminary prototype tests – 0%.
- Redesign of sensor prototype – 0%.
- Final prototype – 0%.
- Final prototype tests – 0%.

## **Nanostructured Electrodes for PEM Fuel Cells**

**EISG Grant Number:** 02-28

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Yushan Yan (909) 787-2068

**Organization:** University of California, Riverside

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of using carbon nanotube based electrode catalyst to significantly increase the utilization rate of platinum in the electrodes of proton exchange membrane (PEM) fuel cells. The increase of platinum utilization will lead to reduction of platinum loading, and consequently reduction of cost of PEM fuel cells.

### **Proposed Outcome:**

- A single cell will be fabricated and tested as part of the project.

### **Anticipated Benefits:**

- Proposed technology has the potential to reduce the platinum loading on the electrodes in PEM fuel cells thus reducing their capital cost and thereby lowering the life cycle cost of power (\$/kWh).
- Fuel cells in general offer many advantages to include: reduced emissions, higher efficiency, elimination of transmission losses, co-generation capability and enhanced grid reliability.

### **Project Status:**

- Projected start date January 1, 2004.
- First progress report due no later than 4 months after start date.

## **New Powerline Control Technology for Lighting and HVAC**

**EISG Grant Number:** 02-26

**PIER Area:** Energy Systems Integration

**Principal Investigator:** Marshall Lester (818) 701-9831

**Organization:** Powerline Control

**Grant Amount:** \$74,318

**Status:** Active

### **Project Description:**

The purpose of this project is to determine the feasibility of using a new low cost powerline communications strategy for electrical load control in commercial, industrial and institutional buildings. Given that all electrical loads are linked to the building's grid via power lines, it is intuitively obvious that tremendous electricity cost savings could be derived by utilizing those same power lines to transmit load control signals. PCS proposes to conduct research-level analysis, testing and evaluation utilizing that environment as a virtual laboratory. Due to the fact that the actual environment in which any powerline communication method is deployed becomes part of the transmission/receiving circuit, there is no substitute for communication/powerline circuit analysis to determine if the proposed technology will meet the performance and reliability demands of the energy management marketplace.

### **Proposed Outcome:**

- A prototype system will be fabricated and field-tested.

### **Anticipated Benefits:**

- Provides a low cost alternative for implementing load control in the industrial and commercial sectors. Current state of the art systems are too expensive or unreliable in high noise environments.
- Newly constructed commercial buildings with load control have demonstrated electrical savings of 20-45%. Given the retrofit capability of the proposed system California could save up to 9,000 gWh/year if used just for lighting control (assumes 150,000gWh/year is consumed by commercial/industrial sectors in CA, 80% of these buildings do not have load control, 30% of load is from lighting, and that 25% savings could be achieved).

### **Project Status:**

- Create the communication/powerline circuit analysis plan – 100%.
- Fabricate the circuit analysis modules – 85%.
- Capture Universal Powerline Bus™ reliability data – 0%.

## **Novel Approaches to Ignition Enhancement of Natural Gas Under Engine-Like Conditions**

**EISG Grant Number:** 02-11

**PIER Area:** Energy Systems Integration

**Principal Investigator:** Fokian N. Egolfopoulos (213) 740-0480

**Organization:** University of Southern California

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to assess the feasibility of using C<sub>2</sub>-hydrocarbons as an ignition enhancer for natural gas under lean burn conditions in an internal combustion engine. These are novel additives, whose use as ignition enhancers has been suggested by investigations of supersonic air-breathing combustion. Compared to H<sub>2</sub>, C<sub>2</sub> ignition enhancers are equally clean burning, and significantly safer to handle. Their principal advantage, however, lies in their economic production, as C<sub>2</sub> fuels can be produced in situ from natural gas by direct catalytic activation. This project explores this approach for improving natural gas ignition, for conditions that are of relevance to power generation by internal combustion engines, be assessed. C<sub>2</sub> ignition enhancers show significant more promise than H<sub>2</sub> technology, as their production is a mature and technologically feasible process. Enhancing the ignition process of natural gas will significantly impact the power generation industry, and will allow for a more efficient reduction of pollutant emissions.

### **Proposed Outcome:**

- Variations of the proposed ignition enhancer will be formulated and tested as part of the project.

### **Anticipated Benefit:**

- Potential to enable the use of low cost internal combustion engines for base load power generation, which would greatly facilitate and accelerate the implementation of distributed generation infrastructure thereby increasing the reliability and security of the grid.

### **Project Status:**

- Investigate the ignition enhancement characteristics of C<sub>2</sub>-hydrocarbons in lean premixed combustion – 30%.
- Evaluate current technologies (Oxidative Coupling of Methane (OCM)) and the economic/technical feasibility of the C<sub>2</sub>-hydrocarbon ignition enhancement technology – 25%.

## **Novel Nanocomposite Carbon Molecular Sieve (CMS) Membranes**

**EISG Grant Number:** 02-17

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Muhammad Sahimi (213) 740-2064

**Organization:** University of Southern California

**Grant Amount:** \$74,997

**Status:** Active

### **Project Description:**

The purpose of this project is to demonstrate the feasibility of utilizing novel Nanocomposite mixed matrix membranes in separations of hydrogen and CO<sub>2</sub> from binary, ternary, and quaternary gas mixtures of relevance to power generation. The use of mixed matrix membranes, which consist of a polymeric matrix, which contains a certain fraction of a molecular sieve material, has been proposed, instead. These membranes are thought to combine the advantages of polymeric membranes (cheap, easily processed) with the advantages of the molecular sieve membranes (superior separation characteristics). It is believed that these membranes will show superior performance in the various power/energy generation related applications outlined.

### **Proposed Outcome:**

- Nanocomposite mixed matrix membranes will be prepared and tested.

### **Anticipated Benefits:**

- Potential to enable significant progress towards solving the gas separation problem in energy generation systems.
- Potential to reduce CO<sub>2</sub> emissions by effectively separating the CO<sub>2</sub> out of flue gas.

### **Project Status:**

- Preparation of CMS nanoparticles – 30%.
- Preparation of nanocomposite CMS Membranes – 25%.
- Test the transport characteristics of the mixed membranes – 10%.



## Plastic Solar Cell

**EISG Grant Number:** 02-16

**PIER Area:** Renewables

**Principal Investigator:** Brian Sager (650) 224-4508

**Organization:** Nanosolar

**Grant Amount:** \$75,000

**Status:** Active

### Project Description:

The purpose of this project is to demonstrate the feasibility of bench-scale fabrication and characterization of a plastic solar cell based on a new nano-technology. In this project, the team will first optimize the processes for a prototype nanostructured photovoltaic cell. Cell efficiency and stability measurements will form the second task. The final task is an assessment of the materials cost associated with this technology. If feasibility of this approach is proven, then follow on work will optimize the process for efficiency and stability, and scale it up to commercial size.

### Proposed Outcome:

- A bench-scale nano-structured photovoltaic cell will be fabricated.

### Anticipated Benefit:

- Potential to provide a system with a 3kW generation capacity at a savings of 80% over current systems with equal capacity. The cost to the consumer may be one fifth that of conventional technology.

### Project Status:

- Optimize processes and polymers for first prototype bench scale cell – 60%.
- Measure cell performance – 10%.
- Assess strategic issues and public benefit/cost ratios – 5%.

## **Pressure Reducing Valve Turbine**

**EISG Grant Number:** 03-08

**PIER Area:** Industrial/ Ag/ Water

**Principal Investigator:** Michael Maloney (425) 861-8870

**Organization:** SOAR Technologies, Inc.

**Grant Amount:** \$75,000

**Status:** Pending

### **Project Description:**

The purpose of this project is to research the feasibility of developing a full-scale power generating pressure reducing valve and validating that the air entrapment in the water stream due to the device mechanics is not detrimental to the operation of the water system.

### **Proposed Outcome:**

- A full-scale prototype device will be fabricated and tested as part of the project.

### **Anticipated Benefits:**

- Potential to produce an additional 100,000 kWh per each developed site at \$.03/kWh and there are 1000 potential sites in CA.
- Proposed technology has the potential to reduce the need for local power utilities to develop additional energy resources thus deferring new plant expenditures, avoiding capital cost, and energy rate increases.

### **Project Status:**

- Projected start date January 1, 2004.
- First progress report due no later than 4 months after start date.

## **Radio Frequency Electrostatic Ignition System Feasibility Demonstration**

**EISG Grant Number:** 02-23

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Paul Freen (321) 264-5944

**Organization:** Eta Tech, Inc.

**Grant Amount:** \$74,998

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of using a new Radio Frequency Electrostatic Ignition System to reduce NO<sub>x</sub> emissions in natural gas fueled reciprocating engines. Engine performance data to be recorded would include combustion characteristics, knock margin, fuel efficiency, and exhaust emissions. This operational test would also produce valuable mechanical and thermal data so that prototypes for field tests could be designed.

### **Proposed Outcome:**

- A prototype ignition system will be fabricated and tested as part of the project.

### **Anticipated Benefits:**

- Potential to help achieve the targeted fuel-to-electricity efficiency of over 50% in reciprocating engines running on natural gas.
- Potential to help reduce NO<sub>x</sub> emissions to 0.01 gm/BHP-hr which exceeds 2007 mandated targets.
- The proposed technology could accelerate the use of low cost reciprocating engines for base load power generation in California.

### **Project Status:**

- Design and machine piston – 85%.
- Design and Procure RFEIS System – 70%.
- Test RFEIS in Combustion Bomb and Hot Fire test – 25%.

## Sealing and Contacting to Novel Integrated Solid Oxide Fuel Cells

**EISG Grant Number:** 02-01

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Scott Barnett (847) 491-2447

**Organization:** Northwestern University

**Grant Amount:** \$74,954

**Status:** Active

### Project Description:

The purpose of this project is to demonstrate the feasibility of using metal brazing alloys for sealing and the electrical contacts within to a novel type of solid oxide fuel cell (SOFC). The basic technical feasibility of the integrated SOFC has been demonstrated recently, so the main feasibility issues remaining are sealing and electrical contacts. The proposed innovation here is to use metallic alloys both for making gas seals and electrical contacts to the fuel cells.

The specific objectives are to determine the feasibility of this approach, to determine the optimal materials and processing procedures, and to fabricate prototype ISOFC stacks complete with seals and contacts, and demonstrate effective performance of the stacks.

### Proposed Outcome:

- Complete integrated Solid Oxide Fuel Cell (ISOFC) stacks using metal brazing for sealing and contacting will be fabricated and tested.

### Anticipated Benefits:

- Potential to accelerate the development of fuel cell technology to achieve the cost and reliability needed in order to be used in distributed generation applications.
- Fuel cells offer the promise of reduced emissions, higher efficiency, increased grid reliability and increased grid power.

### Project Status:

- Progress Reports – 40%.
- Fabrication of Braze joints – 20%.
- Microstructural Evaluation – 10%.

## **Self-Optimized Controllers for Air Conditioners**

**EISG Grant Number:** 02-25

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** T. S. (Jay) Jayadev (408) 257-6465

**Organization:** Energy Savers International

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to determine the feasibility of developing a low cost self-optimizing controller for single-phase air conditioners that reduces electrical consumption by 20%. There is an equal amount of energy that can be saved in the light commercial sector. These energy savings can result in proportionate decrease of pollutants released to the atmosphere by fossil burning power plants.

In a retrofit situation, the component performance characteristics and system behavior are not well defined unlike the situation with the design of new units. The proposed self-optimizing technique intends to overcome this obstacle of insufficient information to operate the air conditioner at optimum efficiency in retrofit applications.

### **Proposed Outcome:**

- A prototype controller will be fabricated and tested as a retrofit unit on a conventional 3-ton air conditioner.

### **Anticipated Benefits:**

- Potential to significantly reduce peak electrical demand caused by air conditioners.
- Potential to save up to 5,000 gWh/year in California based on just residential air conditioner and heat pump savings (assumes 20% energy saving and 100% market penetration). An equal amount could also be saved in light commercial applications.

### **Project Status:**

- Concept definition and selection of air conditioner and optimization – 30 %.
- Develop self-optimizing algorithms – 10 %.
- Conduct performance tests; install optimizing controller – 30 %.
- Final report – 0%.

## Steady State Security Assessment of Deregulated Power Systems

**EISG Grant Number:** 02-05

**PIER Area:** Energy Systems Integration

**Principal Investigator:** Elham B. Makram (864) 656-3378

**Organization:** Clemson University

**Grant Amount:** \$75,000

**Status:** Active

### Project Description:

The purpose of this project is to demonstrate the feasibility of a computational strategy for rapidly assessing the state of the transmission network following possible system contingencies, and would determine post-contingency power flow, bus voltages and loading margins.

With the inception of deregulation, transmission networks are subjected to a host of bilateral transactions, which would influence physical system quantities like real power flows, security margins and voltage levels. For efficient asset utilization and maximization of the revenue, more often than not, transmission networks are operated under stressed conditions, close to security limits. Therefore, a quantitative assessment of the extent to which each transaction adversely affects the transmission network is required. This needs to be done accurately as the feasibility of the power transactions and subsequent decisions (execution, curtailment, pricing) would depend upon the outcome of the analysis. Also considering the large number of transactions occurring in the power market, and the massive sizes of transmission networks, the need for efficient analysis techniques is further highlighted. Thus on the whole, for present-day power systems, security assessment has acquired predominant importance.

### Proposed Outcome:

- A voltage instability indicator and distribution factors using the Jacobian matrix will be developed and utilized.

### Anticipated Benefits:

- Potential to enable the electrical utility to accurately and quickly assess the various state variables of the transmission networks following contingencies that would allow mitigating actions to be taken to ensure the reliability of the system.
- Potential to support the deployment of distributed generation resources by allowing the electrical utility to assess the impact specific distributed generation systems would have on the transmission network if they were brought on line.

### Project Status:

- Validate the applicability of the proposed approach – 100%.
- Implement distribution factors based on AC load – 95%.

## **Unified Power Quality Conditioner Using One-Cycle Control**

**EISG Grant Number:** 02-07

**PIER Area:** Industrial/ Ag/ Water

**Principal Investigator:** Keyue Smedley (949) 824-6710

**Organization:** University of California, Irvine

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to demonstrate the feasibility of using the applicant's patented One-Cycle Control (OCC) circuit design to simplify and reduce the cost of a Unified Power Quality Conditioner (UPQC) that can compensate for reactive power flow, harmonic distortion, and voltage variation/sag. UPQC is a device that is connected in the utility side of the substation to control power flow, regulate the voltage against sag/swell, and eliminate harmonic and reactive current. It is an indispensable element for distributed power generation. The proposed UPQC functions as variable impedance. The value and phase of this impedance can dynamically adjusted to steer the power flow to the right direction as well as regulate the voltage while the frequency characteristics can be adjusted so that the impedance to harmonics is maximized to resist harmonic current flow.

### **Proposed Outcome:**

- A 5KW three-phase bench-scale prototype of One-Cycle Control Unified Power Quality Conditioner (OCC-UPQC) will be fabricated and tested.

### **Anticipated Benefits:**

- Potential to reduce California electrical consumption by 10% if installed in 50% of the utility electrical substations.
- May increase the capacity of the California transmission system by 5%.

### **Project Status:**

- Simulation, Equipment Preparation – 100%.
- Schematic Circuit Design – 100%.
- Prototype Fabrication – 50%.
- Debug and Test – 0%.

**EISG Active Projects from Previous Years**



## **A New Gas Turbine Engine Design for Electricity Generation with Increased Efficiency & Power**

**EISG Grant Number:** 99-09

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** William Sirignano (949) 824-3700

**Organization:** University of California, Irvine

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of an innovative gas turbine design that extends combustion into the turbine sections. This design process has the potential to significantly increase thermal efficiency and specific power output of gas turbines. This project will include a detailed cycle analysis to include turbine inlet temperature, pressure ratio and power distribution in the turbine stages and aerothermodynamic and combustion analysis on the flow through the turbine blades.

### **Proposed Outcomes:**

- Optimized gas turbine design configuration.
- Identify technological obstacles that need to be overcome to advance the concept to the next level.

### **Anticipated Benefits:**

- Increase thermal efficiency of gas turbines to 65 percent, a 15-20 percent increase over conventional engines used for electrical generation. This represents a significant increase in the percentage of the heat energy in the natural gas fuel that is converted to electrical energy.
- Increase the specific power by 100 percent over conventional engines, which allows engines to be built smaller resulting in lower capital costs.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – Under Review.
- Feasibility Analysis Report Initiated.

## **A PCM Slurry System to Decrease Peak Air Conditioning Loads**

**EISG Grant Number:** 00-19

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Randy Clarksean

**Organization:** Leading Technology Designs, Inc.

**Grant Amount:** \$73,457

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of developing a phase change slurry (PCM) mixture to be used in an air conditioning (a/c) unit to absorb peak a/c loads. The slurry is a mixture of water, emulsifier, and paraffin. The innovations pursued here are the development of a high concentration PCM Slurry and the development of a low-cost system to absorb A/C loads and to reject that energy to the earth. The project goal is to produce stable, high-volume fraction PCM slurry and demonstrate that this slurry can be pumped through a heat exchanger and stored.

### **Proposed Outcomes:**

- Develop and demonstrate a PCM slurry mixture capable of absorbing 30% or greater of the peak A/C load.
- Fabricate bench-scale PCM system and perform system tests.

### **Anticipated Benefits:**

- A system capable of reducing a/c loads by 30% or more.
- A unit with a production cost range of \$40-\$160 per kW for heating.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## Actively Controlled Jet Injection in Gas Turbine Engine

**EISG Grant Number:** 99-11

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Ann Karagozian (310) 825-5653

**Organization:** University of California, Los Angeles

**Grant Amount:** \$74,899

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of using actively controlled dilution air jets that deliver pulsed air perpendicular to the intake air flow in the primary zone of a gas turbine's burner to rapidly produce a lean mixture. Dilution air jets are used in gas turbines for temperature control and NO<sub>x</sub> reduction through air-fuel mixture ratio control. This project builds upon prior work that modeled pulsed transverse jet flow, and will develop control strategies based on simulations followed by experimental validation using a bench-scale combustor.

### Proposed Outcomes:

- Optimal open and closed loop control strategies for pulsed transverse dilution jets to achieve maximum reduction of NO<sub>x</sub> emissions.
- Combustor design specifications for incorporating pulsed air jets, actuators and sensors.

### Anticipated Benefit:

- Reduce NO<sub>x</sub> emissions in gas turbines 50 percent by maintaining a constant, lean air-fuel mixture.

### Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – Under Review.
- Feasibility Analysis Report Draft – Under Review.

**Advanced Generation of H<sub>2</sub> and CO from Improved Methane-Carbon Dioxide-Steam Reforming Process, for use as Fuel and Methanol, Gasoline Synthesis Gas**

**EISG Grant Number:** 00-32

**PIER Area:** Energy Systems Integration

**Principal Investigator:** Zoe Ziaka (818) 893-4292

**Organization:** Zoe Ziaka

**Grant Amount:** \$75,000

**Status:** Active

**Project Description:**

The purpose of this project is to research the feasibility of using a catalysis reaction to convert waste gas streams containing CO<sub>2</sub> and methane to CO and hydrogen, of which the hydrogen could be used to power fuel cells. This technology will utilize and upgrade CO<sub>2</sub>-containing methane streams such as landfill, sour, and waste type gases. CO<sub>2</sub>-innovative abatement processes, especially within in-situ reactors via relevant reactions and catalysis systems is under increased consideration in current and future industrial efforts, and is considered an additional benefit of this proposed work. This project will develop a new, effective reforming and catalysis system that converts the above feedstocks and delivers purified grade gas required for fuel cell applications.

**Proposed Outcomes:**

- Developed selective catalyst.
- Production of synthesis gas from reforming of secondary and waste hydrocarbon streams.
- Completed evaluation of the process for integration to turbines, fuel cells or synthesis gas.

**Anticipated Benefits:**

- Increased production of Hydrogen.
- Projected energy savings in the range of 20-30%.
- Abatement of CO<sub>2</sub> mixtures, which lowers greenhouse gas emissions.

**Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## **AGF Pasteurization Process Assessment, Orange County, CA**

**EISG Grant Number:** 00-03

**PIER Area:** Renewables

**Principal Investigator:** Dennis Burke (360) 923-2000

**Organization:** Cyclus Envirosystems, Inc.

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of a pilot plant using an anoxic gas flotation pasteurization process to more efficiently convert organic materials such as agricultural waste, sewage sludge, and manure into fuel gas and Class A residual solids. The innovative process can use the heat recovered from power generation to increase the quantity of organic material converted to gas while producing disinfected nutrient rich, residual. More gas is produced, fewer residual solids must be disposed, and public health is protected while the capital and operating costs of waste treatment and power generation is reduced.

The biochemical process is the anoxic gas flotation (AGF) pasteurization process that utilizes high temperature waste heat from a turbine, microturbine, or engine generator set to increase the rate and quantity of organic material converted to gas. A 40% improvement in solids converted to gas has been shown at laboratory bench scale. The AGF pasteurization process also reduces the amount of process energy required when compared to conventional or thermophilic digestion processes and the quantity of the concentrated, nutrient rich, residual product to be disposed. The disinfected residual product can be given or sold to the general public, locally, without restriction.

### **Proposed Outcomes:**

- Pilot plant capable of processing 400 gpd of sewage sludge.
- Optimized methodology for operating processing plant.
- Feasibility analysis based on pilot plant performance.

### **Anticipated Benefits:**

- Up to 40% increase in conversion rate of organic solids to biogas.
- Increase fuel gas production by 25%.
- Reduce solids processing costs by 60%.
- Produce a disinfected Class A residual product that does not require landfill disposal.

### **Project Status:**

- Design – 100%.
- Pilot Plant Construction – 100%.
- Start-up and Initial Operation – 80%.
- Monitoring and Analysis of Process – 50%.
- Evaluation of Process Performance – 0%.

## **Agripower-Renewable Generation**

Agricultural Waste & Forest-Thinnings-To-Energy

**EISG Grant Number:** 01-10

**PIER Area:** Renewables

**Principal Investigator:** Harvey F. Brush (916) 261-2981

**Organization:** PMC Biomass, LLC.

**Grant Amount:** \$74,605

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of a new biomass combustion turbine that uses an open Brayton Cycle and modular design. This project will perform component and system testing with particular emphasis on the fuel feed and fluidized bed combustion control system. Farms and orchards generate nearly 8 million dry tons of agricultural waste each year and use about 175 trillion Btu's annually. These biomass wastes represent some 120 trillion Btu's that could take the place of natural gas in generating process heat or electricity. Specific goals of the Agripower are to:

Utilize in-woods waste as a fuel while reducing or eliminating transportation costs.

Create energy (possible 120 trillion Btu's annually just from farms and orchards) from agricultural waste with relief of dependency on the grid for many agricultural industries.

The electricity can be used to power machinery to create other value-added products (e.g. using a mini-mill in the woods to manufacture cants for pallets, operate a chipper or hammer mill, and the drying of agricultural matter for fuel). Excess electricity can then be used to power agricultural plants or in the in-woods application, sold back to the local electric utility as a source of green power or distributed generation.

### **Proposed Outcomes:**

- A 200kW biomass powered prototype generator.
- Computerized control software.
- Feasibility analysis of fuel feed system based on performance of prototype system.

### **Anticipated Benefits:**

- Provide a cost effective and environmentally friendly solution to converting a variety of waste biomass feedstocks into electricity and heat. CA produces about 9.8 Mil tons of annual forest, mill and urban wood residue, which is the primary targeted feedstock.
- Projected cost (capital and operating) of power generation is \$.06/kWh without cogeneration. With cogeneration the cost can be further reduced.

### **Project Status:**

- Fuel Feed System – 25%.
- Design and Program Instrumentation, Controller – 48%.

## **An Innovative Approach to Stabilize the Thermal Conductivity of Air Plasma-Sprayed Thermal Barrier Coatings**

**EISG Grant Number:** 00-22

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Rodney Trice (765) 494-6405

**Organization:** Purdue University

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of increasing the overall efficiency of land-based turbines via an innovative materials solution employing micro-structurally designed thermal barrier coatings (TBCs). Sintering (i.e. densification of the coating) causes the thermal conductivity of thermal barrier coatings to increase by as much as 100-150% during service, greatly reducing the ability of the thermal coating to protect the underlying structure from temperature extremes. For example, the thermal conductivity of an air plasma-sprayed coating will increase from 1.2 W/m-K to 2.3 W/m-K after 50 hours exposure to 1200°C (2192° F) heat. The end result of an increase in the thermal conductivity of the coating is that the gas turbine must be operated at lower temperatures or more cooling must be provided for the hot components. Either of these results decreases the efficiency of the electricity production.

To inhibit sintering, the coating will be altered at the atomic level by changing the chemical properties of the TBC via the addition of select dopants. The basic mechanism for inhibiting sintering is based on the "Space Charge Theory". This theory predicts that added dopants will tend to segregate to grain boundaries to keep the crystal electrically neutral. The effect of the cations (positively charged ions) accumulating at the grain boundaries is to prohibit boundary movement, a necessary condition to keep sintering from occurring. The result is that the microstructure that gives rise to the low thermal conductivity is stable because sintering of the coating is prohibited. The goal is a 100% reduction in the long-term thermal conductivity of these microstructurally designed coatings.

### **Proposed Outcomes:**

- Produce a thermal barrier coating capable of maintaining a thermal conductivity of 1.2 W/m- K over 500 hrs at 1400°C (2552° F).
- Produce colloidal suspensions of 1-mm diameter stabilized zirconia and dopants that can be plasma sprayed without agglomeration.
- Optimize the plasma-spray parameters for each stabilized zirconia/dopant to satisfy the following criteria: (a) a high degree of atomic mixing occurs, (b) 1 mm deposition rates are observed, and (c) coatings contain less than 15% porosity.
- Reduce the amount of sintering that occurs in the coatings by reducing grain growth by 100%.

### **Anticipated Benefits:**

- Increase of combustion temperature by 50°C (122° F).
- An increase in efficiency of 3-4%.
- Increased reliability of the coating.

**Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.



## **An Integrated Anti-Fouling Technology for Energy Efficient Chillers**

**EISG Grant Number:** 00-23

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Young Cho (856) 424-8118

**Organization:** J&D Thermo-Fluid Technology, Inc.

**Grant Amount:** \$74,953

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of developing a solenoid-induced precipitation and side-stream filtration for chillers, which will cause excess mineral ions to precipitate out thus reducing scaling of chillers and raising their efficiencies. The electricity consumed by medium to large size chillers (200 – 2,000 tons) is a major portion of total electric consumption in California and worldwide. These chillers are often water cooled, and fouling in chiller tubes (or more specifically condenser tubes) decreases chiller efficiency, thereby substantially increasing the consumption of electricity, particularly during the cooling season. Integrated anti-fouling (IAF) technology can prevent or mitigate fouling in condenser tubes enabling chillers to run more efficiently during the entire cooling season. This will result in substantial and continuous savings in electricity. Another major benefit of the IAF technology is the substantial reduction of peak electricity demand levels generated by space cooling systems during the hottest days of the year.

The IAF technology uses solenoid-induced precipitation and side-stream filtration. Solenoid-induced precipitation utilizes a square-wave pulsing current to create time-varying magnetic fields, which in turn produce an induced pulsating electric field in the circulating water. Excess mineral ions such as calcium and magnesium in cooling-tower water precipitate out as mineral salts, providing nucleation sites for other dissolved mineral ions. As the cooling-tower water is continuously circulated, the precipitated seed crystals grow into larger particles, which are then removed by side-stream filtration. When the scale-causing mineral ions are removed from the cooling-tower water, fouling at the condenser tubes can be prevented or significantly mitigated, resulting in direct electricity savings.

### **Proposed Outcomes:**

- Develop anti-fouling technology for medium-to-large chiller applications.
- Demonstrate feasibility of the technology.

### **Anticipated Benefits:**

- Increased water savings.
- Increased electrical savings.
- Reduced peak electricity demand.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## **Application Feasibility Study of Gravitational Non-equilibrium Heat Pumps and Heat Engines**

**EISG Grant Number:** 00-21

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Thomas C.B. Smith (441) 223-2432

**Organization:** Thomas C.B. Smith

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of developing a gravitational heat engine (GHE) where the fundamental operating principle is entirely dependent on at least part of the system never reaching equilibrium. The Gravitational Heat Engine is a Rankine cycle with one moving part. A comprehensive understanding of GHE properties for the purposes of engineering applications does not yet exist. This project will concentrate on investigating the feasibility of GHEs for electricity generation as a cogenerative engine for extracting energy from any low-grade heat source.

### **Proposed Outcomes:**

- Construct functional prototype.
- Demonstrate system efficiency of between 2 and 10% converting solar energy to electricity.
- Heat engine fueled by solar and low temperature waste heat.
- Feasibility analysis based on performance of functional prototype.

### **Anticipated Benefits:**

- Unit production cost range of \$1500-\$7500 per kW for electricity production.
- Unit production cost range of \$40-\$160 per kW for heating.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## **Attic and Crawl Space Ventilation Air Heat Exchanger**

**EISG Grant Number:** 99-24

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** G Brown (541) 346-5647

**Organization:** University of Oregon

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of developing a low-cost, air-to-air heat exchanger capable of 50% or greater efficiency for use in residential and small commercial buildings. Utilizing a heat exchanger to temper the air before conditioning it will result in reduced building loads leading to down sizing of the HVAC equipment. It will also reduce energy consumption and electrical demand. The primary problem of current heat exchangers is how to reduce their cost so energy savings can pay back the initial cost of the heat exchanger in a short period of time. One solution to this problem is to exploit underused areas in residential and small commercial buildings - the crawl space or attic - to increase heat exchanger surface area and to use thin film tubes to reduce cost. Existing heat exchangers concentrate on reducing overall size while maintaining efficiency. Competitive heat exchangers include finned-tube, plate, heat pipe, and enthalpy, which are more expensive.

### **Proposed Outcomes:**

- Two or more full-scale prototype air-to-air-heat exchanges.
- Hardware connection designs for conventional HVAC equipment.
- Feasibility assessment based on prototype performance testing.

### **Anticipated Benefits:**

- Potential energy savings of 825 GWh/yr in California assuming only 10% and 1% market penetration in the residential and commercial building sector respectively.
- Reduce the installed cost of air-to-air heat exchangers by up to 90%.
- Improve the indoor air quality in modern airtight residential housing by providing a cost effective device for conditioning outside ventilation air.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Draft Final Report Submitted.
- Feasibility Analysis Report Drafted.
- EISG Program Administrator's Review of Final Report Draft in Process.

## **Automating Window Sunshade Control: Toward the Zero Energy House**

**EISG Grant Number:** 01-28

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Murray Milne (310) 454-7328

**Organization:** University of California, Los Angeles

**Grant Amount:** \$74,685

**Status:** Active

### **Project Description:**

The purpose of this project is to demonstrate the feasibility of a new kind of intelligent thermostat that incorporates outdoors temperature sensors to control automated sunshades to reduce the heat load on air conditioners in the summer. This project will demonstrate the feasibility of a new kind of an intelligent window sunshade controller that can minimize cooling and heating energy costs for California ratepayers. Developing this thermostat-microprocessor to control the operation of shading elements on the building envelope is an important step towards creating a Zero Energy Home.

Already on the market, especially in Europe, are various electrically operable sun control devices. These include awnings that extend and retract, vertical exterior operable louvers, interior operable draperies and venetian blinds. However, none of them has any type of intelligent controller, similar to the microprocessor-thermostat developed in a previous EISG project that could read outdoor temperatures and operate shading devices in order to optimize indoor temperatures.

The project result will be the development of a new enhanced thermostat-controller, a computer program optimized for the best indoor air temperature control, data demonstrating the differences between interior or exterior shades, and recommendations regarding the best way to install and control automated sun controls. An added goal will be to try to interest either a thermostat manufacturer or an automated shade manufacturer into adding such a device to their product line.

### **Proposed Outcome:**

- A microprocessor controlled thermostat that can sense both indoor and outdoor temperature will be built, programmed and tested as part of the project.

### **Anticipated Benefits:**

- Potential to reduce residential air conditioning costs by reducing the solar heat gained through windows.
- May allow the shades to automatically adjust to weather changes without the need of human interaction.

### **Project Status:**

- Survey Literature – 100%.
- Acquire Commercial Sunshade – 100%.
- Refurbish Test Cells – 100%.
- Install Sunshade in Test Cell – 100%.
- Define New Micro-processor Controller Logic – 100%.
- Build New Microprocessor Controller – 100%.
- Run Full Scale Tests for Summer Cooling – 50%.

## **Biofiltration Abatement of Landfill Gas Energy Exhaust Pollutants**

**EISG Grant Number:** 01-01

**PIER Area:** Environmental Area

**Principal Investigator:** Don Augenstein (650) 856-2850

**Organization:** Don Augenstein

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of a biofiltration strategy to clean the exhaust of an internal combustion engine running on landfill gas. Landfill solid waste will be used as the primary contact medium in the biofiltration system. If this technique proves viable as expected, laboratory data will be extrapolated to full-scale system performance and costs.

### **Proposed Outcomes:**

- Cost and performance projections will be made based on data obtained.
- Plan for full-scale testing if results from this project are encouraging.

### **Anticipated Benefit:**

- Allow recovery of about 300-500MWe of landfill gas electric generation potential that is now stalled in California due to excessive pollutants in energy equipment emissions.

### **Project Status:**

- Assemble laboratory reactors – 100%.
- Develop analytical techniques for exhaust pollutants of greatest concern – 100%.
- Examine abatement kinetics under various gas flow regimes and biofilter characteristics – 50%.
- Estimate cost for application of full-scale biofiltration – 0%.
- Plan large-scale tests – 30%.

## **Carbon Foam Based NO<sub>x</sub> Biofilter**

**EISG Grant Number:** 00-04

**PIER Area:** Environmental Area

**Principal Investigator:** Daniel Chang (530) 752-2537

**Organization:** University of California, Davis

**Grant Amount:** \$74,989

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of using Ultramet carbon foam as a packing material in a post combustion NO<sub>x</sub> biofilter to increase efficiency and reduce capital cost. However, biofiltration to control NO<sub>x</sub> is difficult because of mass transfer rate limitations. Newly engineered materials developed for other applications, e.g., Ultramet carbon foam for catalyst supports, can be tailored to meet the needs of an inexpensive, light weight, inert, biofilter packing that provides a high specific surface area (surface-to-volume) to greatly increase the mass transfer rate. UCD believes that the key to economical biological treatment of NO is to maximize the specific surface that can support the necessary biofilm without clogging. The objective of this work is to conduct energy-related environmental research that demonstrates the feasibility of developing a commercially viable NO<sub>x</sub> biofilter.

### **Proposed Outcomes:**

- Subscale prototype biofilters.
- Design parameters for system scale up.
- Feasibility analysis based on performance of prototype biofilters.

### **Anticipated Benefits:**

- Reduce the cost of NO<sub>x</sub> removal by at least 50% to \$0.40/lb- NO<sub>x</sub>.
- Provide cost effective means of lowering emissions from small-distributed generation units.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## **Closed Cycle Valved Cell Heat Engine**

**EISG Grant Number:** 00-01

**PIER Area:** Renewables

**Principal Investigator:** Joseph Bland (916) 429-6252

**Organization:** Joseph Bland

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of fabricating a low cost heat engine that is capable of operating efficiently on low-temperature external heat sources. This project will construct, test and analyze a proof-of-principle prototype of a closed-cycle Valved Cell Engine (VCE). The objectives of the project are to determine if it is technically and economically feasible to fabricate the proposed engine design and to establish that the proposed design is capable of operating effectively from external heat sources in the range of 500-800<sup>0</sup> F. The VCE is targeted at low temperature heat sources because of its unique ability to deliver very high work output per pound of working fluid (about 50% greater than that of a comparable Stirling engine). The VCE can operate effectively and efficiently at these very low source temperatures. This makes it an ideal heat engine for solar, geothermal and waste heat applications. The VCE's power density also means it can tap efficiently into very small heat sources.

### **Proposed Outcomes:**

- Prototype closed-cycle valved cell engine.
- Feasibility analysis based on prototype performance.

### **Anticipated Benefits:**

- Low cost heat engine design capable of generating 2-3 kW from concentrated solar or other low temperature sources.
- 0% higher work output per pound of working fluid compared to a sterling engine.
- Low capital cost with 3-5 year pay back period.
- Zero emissions when operated from solar energy.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## Commercial and Residential Super Insulated Phase Change Material Water Heater

**EISG Grant Number:** 00-18

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Nick Wynne (937) 376-8233

**Organization:** VacuPanel, Inc.

**Grant Amount:** \$75,000

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of developing an innovative electric water heater that increases operating efficiency by incorporating vacuum insulation and phase change materials. This will be accomplished by means of an innovative, advanced technology water heater design which uses the advantages provided by vacuum insulation panel (VIP), and phase change material (PCM) technologies to reduce the operating expense and improve the efficiency of maintaining heated water. Energy stored in heated water statically awaits demand throughout the day, and is frequently wasted due to stand-by losses.

The proposed water heater will be designed to optimize the storage of heat in a phase change material (PCM), through which cold water passes to become heated, use VIP to retain the heat in the PCM over a long period and be recharged (heated to change phase) at less expensive, off-peak electricity or natural gas. Such a heater will provide more efficient and lower cost hot water. The operating cost is reduced through off-peak energy savings, reduced stand-by energy losses, and long life.

### Proposed Outcomes:

- Full scale prototype hot water heater.
- Feasibility analysis based on performance of prototype system.

### Anticipated Benefits:

- Increase the average water heater life from 7 years to 50 years.
- Increase water heater efficiency by 6% by reducing standby losses.
- Provide increased ability to shift energy consumption to off-peak hours.

### Project Status:

- Review cost, availability, characteristics of PCM – 100%.
- Review heat exchanger and submersible pump options – 90%.
- Evaluate effectiveness of vacuum panel insulation – 90%.
- Evaluate techniques for circular seals in Vacuum panel insulation – 100%.
- Evaluate improved design, manufacturability of cylindrical vacuum panel insulation – 100%.
- Develop options for installing thermal breaks on water heater protrusions – 100%.
- Benchmark PCM/Heat exchanger combinations – 20%.
- Build prototype – 0%.
- Test prototype – 0%.



## Composite Architectures for Sub-600C Solid Oxide Fuel Cells

**EISG Grant Number:** 99-35

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Lutgard De Jonghe (510) 486-6138

**Organization:** University of California, Berkeley

**Grant Amount:** \$70,811

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of producing a composite solid oxide fuel cell (SOFC) membrane assembly that optimally combines reforming and catalytic functions with high cathode and anode electronic conductivity. The methods used involve colloidal processing techniques, offering potentially low fabrication costs. The ceramic SOFC membranes have a novel composite architecture that optimally combines the reforming and catalytic functions with high electronic conductivity, through the choice of materials and microstructure. The methods by which the composite membranes are produced involve colloidal processing and common ceramic processing techniques, thereby avoiding costly production steps, and therefore significantly enhance the feasibility of the concept.

Decreasing the temperature of operation of an SOFC, down from the current 1000°C operation, can significantly alleviate materials compatibility and durability problems in the SOFC stack, reducing the cost of this technology while maintaining its advantages. Increasing the materials and system reliability and lowering cost of SOFCs are essential factors in enabling broad commercial introduction of the energy efficient SOFC technology, both at the residential and small to intermediate industrial scale.

### Proposed Outcomes:

- Prototype fuel cell membrane with an overall membrane resistance of less than 1 ohm/cm<sup>2</sup> that can operate efficiently at or near 600°C.
- Fabrication process for low-cost fuel cell membranes.
- Feasibility assessment based on prototype performance testing.

### Anticipated Benefits:

- Reduce the manufacturing cost of solid oxide fuel cells as a result of reducing the operating temperature that reduces the need for expensive materials.
- Increase the reliability of solid oxide fuel cells by reducing material compatibility problems that are caused by high operating temperatures.

### Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – Under Review.
- Feasibility Analysis Initiated.

## Controlling Fouling with Rice Straw Blends in Biomass Boilers

**EISG Grant Number:** 00-20

**PIER Area:** Renewables

**Principal Investigator:** Charles E. Leshner

**Organization:** University of California, Davis

**Grant Amount:** \$73,858

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of developing a test plan that will determine the allowable additions of rice straw to wood-based fuels in order to minimize alkali volatilization and thus to restrict fouling potential. The California biomass power industry is facing increasing environmental and economic pressures to utilize herbaceous fuels, such as rice straw. These fuels are expected to increase the potential for slag deposition and fouling of heat exchangers that lead to a reduction in the efficiency of biomass power generation and to an increase in operating costs. However, new experimental results show that the addition of rice straw to conventional biomass fuel types can reduce alkali volatilization.

The test plan will determine the allowable additions of rice straw to wood-based fuels in order to minimize alkali volatilization and thus restrict fouling potential. The fusion temperatures and rates of potassium volatilization of slag formed from blends of rice straw and wood ashes will be established. These data will be used to formulate predictive models for the high-temperature fouling potential, the physical properties, and tenacity of slag deposits from fuel blends. From the results, practical predictions regarding tolerable fuel blends and proposed new combustion strategies utilizing unconventional and lower cost blends of herbaceous and conventional wood fuels will be proposed. These predictions will be tested in a fluidized bed combustor.

### Proposed Outcomes:

- Quantify fouling potential of rice straw fuel blends.
- Determine optimal rice straw fuel blends for reducing fouling.
- Demonstrate that a minimum addition of 10% rice straw can be accomplished without a proportional increase in fouling rate.

### Anticipated Benefits:

- Increased fuel flexibility for fluidized bed combustor.
- Reduced maintenance costs.

### Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## **Corrosion Resistant Coating for Carbonate Fuel Cell Components**

**EISG Grant Number:** 00-05

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Yuhong Huang (818) 727-9786

**Organization:** Chemat Technology, Inc.

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of increasing the life of molten carbonate fuel cells by using a sol-gel coating of  $\text{LiCOO}_2$  on the NiO cathode and cathode current collector to reduce corrosion. The primary objective of this proposed research is to solve one of the most serious problems in molten carbonate fuel cells: corrosion of cathode current collector and lithiated NiO cathode, which has been a major lifetime-limiting factor. In this proposed project, a sol-gel coating process will be developed to improve the performance of cathodes and cathode current collector. By carefully selecting the coating materials, the corrosion resistance can be enhanced dramatically. Consequently, the lifetime and power generation efficiency of this fuel cell can be improved simultaneously.

### **Proposed Outcomes:**

- Material samples will be fabricated with sol-gel coating.
- Methodology for applying sol-gel coating.
- Feasibility analysis based on performance of material samples.

### **Anticipated Benefits:**

- Increase fuel cell life by 100%.
- Increases capital cost of cathode and current collector by less than 2%.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## **Cost Effective Lost Distortion Adjustable Speed Drive**

**EISG Grant Number:** 99-34

**PIER Area:** Industrial/ Ag/ Water

**Principal Investigator:** Arthur Iverson (408) 354-7972

**Organization:** Spinel LLC

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of a new, low cost, pulse width modulated (PWM) inverter design capable of producing pure waveforms for controlling adjustable speed drive (ASD) motors. The focus of the project is to establish the feasibility of building adjustable speed drives that do not produce the distorted waveforms that cause premature motor failures such as those generated by the ASDs now in use. Electric motors are designed to run on sinusoidal utility power (60 Hz). An advanced ASD, employing high frequency switching >60kHz, allows the synthesis of essentially pure sine waves that are cleaner than those received from the Utility and provides normal motor life. Agricultural uses of ASD motors include programmed pump irrigation, and uses in produce conveyers and processing systems. ASD pumps are used to control water flow in water transport and sewage treatment plants.

### **Proposed Outcomes:**

- A prototype motor controller will be fabricated and tested on a three-phase 5 HP motor.
- Prototype three-phase inverter capable of producing pure variable frequency sine waves with current harmonics less than 5% and efficiency greater than 92% regardless of cable length.
- Feasibility assessment based on prototype performance testing.

### **Anticipated Benefits:**

- Low cost solution to eliminating premature ASD motor failures due to leading edge PWM pulse spikes which cause premature insulation failure.
- Eliminate or minimize costly harmonic filters and associated engineering analysis that is currently required for harmonic sensitive ASD installations.
- Significantly increase ASD market penetration which is currently only 9% due to lack of confidence in the technology.

### **Project Status:**

- 10 kW high frequency, low harmonic AC-DC converter – Design – 95%.
- Construction & debugging – 20%.
- Demonstrate – 100%.
- 10kW single phase (one leg of three phase).
- Design – 0%.
- Construction & debugging – 0%.
- Interface with converter – 0%.
- Test and operation – 0%.

## **Desiccant Enhanced Indirect/Direct Evaporative Cooling System**

**EISG Grant Number:** 01-22

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** William A. Belding (530) 268-7397

**Organization:** Innovative Research Enterprises

**Grant Amount:** \$74,900

**Status:** Active

### **Project Description:**

The purpose of this project is to demonstrate the feasibility of a new air conditioning design that incorporates indirect/direct evaporative cooling and dehumidification with gas regeneration. The proposed indirect/direct system employs desiccant components within the indirect cooling stage, thus simultaneously dehumidifying and cooling the process air. With the proposed technology, a single component will perform at improved efficiency, the functions now performed by a desiccant dehumidifier and a heat exchanger. Having improved performance over existing techniques, the system can be used as a total cooling solution for western climates and eliminate the need for conventional vapor compression systems.

### **Proposed Outcome:**

- A prototype heat exchanger will be built and tested as part of the project.

### **Anticipated Benefits:**

- System design capable of SEER rating greater than 30 as opposed to traditional vapor compression units, which have a SEER of 10-16.
- Potential to shift some of the peak electrical load used for AC to natural gas.
- May increase comfort and indoor air quality by supplying up to 100% outdoor air to the conditioned space.

### **Project Status:**

- Develop Desiccant Application Techniques for Heat Exchanger Partitions – 100%.
- Fabricate Heat Exchanger – 100%.
- Do Performance testing – 95%.
- Determine Cost Benefits – 60%.

## Development of a Borehole Seismic Receiver Array for Geothermal Wells

**EISG Grant Number:** 99-37

**PIER Area:** Renewables

**Principal Investigator:** Bjorn Paulsson (562) 694-9598

**Organization:** Paulsson Geophysical Services

**Grant Amount:** \$75,000

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of developing a borehole seismic receiver array for geothermal wells capable of operating in a temperature range of 200°-250°C. Existing short and low temperature arrays severely limit the use of borehole seismology in geothermal energy exploration. This project will address this shortcoming by developing a much larger seismic receiver array that can operate at much higher temperatures.

Large borehole seismic receiver array technology will make it possible to routinely map high permeability zones and monitor production in fractured geothermal reservoirs with a resolution in the range of 3 to 6 ft (1 – 2 m) using 3D VSP, passive seismic monitoring and cross well seismic techniques. Three component arrays allow recording of both P and S wave data that together provide information on the location, the size and the preferred direction of fractures and fracture zones in the reservoir. The fracture information is the key information that will help determine the directional permeability of the reservoir and how to economically produce its geothermal resources.

### Proposed Outcomes:

- Cable design capable of withstanding operational temperatures of 200°–250°C.
- A prototype five-level high-temperature borehole seismic receiver array.
- Feasibility assessment based on prototype performance testing in field setting.

### Anticipated Benefits:

- Ability to record P and S wave data that enable the mapping of fracture zones in high-temperature geothermal reservoirs.
- Enable more efficient management of existing geothermal reservoirs.
- Reduce the number of wells needed to develop a geothermal resource.
- Allow economic development of lower temperature and lower permeability geothermal fields.

### Project Status:

Project term has been extended due to delay in manufacturing of High Temperature Cable to project specification.

- Design – 75%.
- Vendor selection – 50%.
- Manufacturing – 10%.
- Environmental testing of components – 0%.
- Field testing of completed assembly – 0%.
- Processing of recorded data – 0%.

## **Development of a PEM Electrolyzer: Enabling Seasonal Storage of Renewable Energy**

**EISG Grant Number:** 00-25

**PIER Area:** Renewables

**Principal Investigator:** Peter Lehman (707) 826-4345

**Organization:** Humboldt State University Foundation, Schatz Energy Research Center

**Grant Amount:** \$74,478

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of developing a proton-exchange membrane (PEM) electrolyzer capable of generating a minimum of three standard liters per minute of hydrogen at 2,000 pounds per inch<sup>2</sup> gauge pressure, using approximately one kilowatt of power. This is an important first step in the commercialization of high-pressure PEM technology.

Hydrogen can be produced using electrolyzers powered by renewable electricity, stored, and converted back to electrical energy as needed using a fuel cell. Hydrogen can be used as long-term, seasonal energy storage at reasonable cost, while other energy storage technologies including batteries, pumped hydroelectric storage, compressed air, flywheels, ultracapacitors, and superconducting magnets do not offer equitable storage capacity and cost that can be achieved with hydrogen. Hydrogen can be stored cryogenically as a liquid, chemically as a metal hydride or physically as a compressed gas.

### **Proposed Outcomes:**

- Determine optimal current density and temperature.
- Fabricate a prototype, proton exchange membrane electrolyzer with high-pressure hydrogen output.

### **Anticipated Benefits:**

- Eliminate the need for mechanical compression.
- Reduce mechanical complexity of electrolyzers.
- Reduce cost versus alkaline electrolyzers over a wide range of plant sizes.
- Reduce maintenance needs versus current electrolyzers.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## **Development of an Effective Fire-Shield for Powerpoles by Custom Tailoring a Mineral Polymer Material**

**EISG Grant Number:** 01-13

**PIER Area:** Energy Systems Integration

**Principal Investigator:** Clem Hiel (626) 351-2082

**Organization:** Composite Support & Solutions, Inc.

**Grant Amount:** \$74,510

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of developing a low cost fire shield for power poles made out of a newly developed mineral polymer material and glass fibers. A pole Fire-Shield is simply a protective sleeve applied around a wood pole, starting at ground level and extending up to about three times the height of the surrounding brush. These pole fire shields are of vital importance to the California utilities because they effectively increase the survivability of electrical transmission and distribution poles during raging brushfires. Electrical utility experience substantiates that fires consume unshielded poles in a few minutes. This creates an important energy delivery problem in the form of extended outages suffered by the California consumers because the effort of setting new poles typically takes one to several weeks to complete.

BlazeBarrier, Inc. will create a novel Fire-Shield based on its newly developed Inorganic Mineral Polymer (MIP), that is non alkaline. This Mineral Polymer is made at room temperature, using a two-phase system, which develops into a durable three-dimensional network structure. The fact that the material is made at room temperature contributes to its lower cost, energy efficiency, and environmental benefits.

The basic MIP material has the one disadvantage that cracks readily propagate because the material has no inherent crack arresting mechanism, to stop a crack once it has initiated. BlazeBarrier's research proposes to solve this problem by creating a composite material that consists of glass fibers distributed throughout the MIP material. This custom tailored material will blend the excellent fire barrier properties of the Mineral Polymer with the toughness properties needed for it to function as a pole Fire-Shield.

### **Proposed Outcomes:**

- Prototype test samples of new fire-shield material.
- A comprehensive mathematical model.
- Feasibility analysis based on performance of prototype material.

### **Anticipated Benefits:**

- Potential low cost alternative to the current expensive and less effective pole shields that are being used in place of the asbestos shields that are being removed for environmental reasons.
- Potential to increase grid reliability by reducing outages caused by fires near transmission lines.



**Project Status:**

- Requirements Definition – 100%.
- Trade Study – 100%.
- Fabricate and Test Toughening – 100%.
- Comparative Fire Testing – 100%.
- Correlation – 0%.
- Cost & Quantitative Estimates of Improvements – 0%.

## **Development of Optimum Design Configuration and Performance for Vertical Axis Wind Turbine**

**EISG Grant Number:** 00-17

**PIER Area:** Renewables

**Principal Investigator:** Hamid R. Rahai (562) 985-5132

**Organization:** California State University, Long Beach Foundation

**Grant Amount:** \$69,781

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of improving the efficiency of vertical axis wind turbines by optimizing the blade design through numerical modeling. Two subscale prototypes will be fabricated and tested, one with an optimized mono airfoil and one with an optimized two element airfoil. The objective of the project is to improve the performance of vertical axis wind turbines for residential and commercial applications. Recent studies suggest that increasing the efficiency of this type of turbine requires increased contribution from the lift force to generate torque. The present proposal will implement numerical techniques for optimizing highly cambered thin airfoils (which have similar shapes as high lift airfoils) for use in a high-efficiency, vertical-axis wind turbine. Using optimized blades, scaled model turbine will then be built and tested in the wind tunnel.

### **Proposed Outcomes:**

- Two subscale prototype wind turbines with optimized blades.
- Methodology for optimizing blade designs.
- Feasibility analysis based on performance of prototype turbines.

### **Anticipated Benefits:**

- Increase vertical-axis wind turbine efficiency by 20 - 30%.
- Cost-effective, vertical-axis wind turbines that could be used for distributed generation applications.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## Development of Single Fan Multi-Stack Exhaust Systems

**EISG Grant Number:** 01-27

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Mingsheng Liu (402) 554-2173

**Organization:** University of Nebraska

**Grant Amount:** \$74,805

**Status:** Active

### Project Description:

The purpose of this project is to demonstrate the feasibility of a single fan multi-stack laboratory exhaust system that reduces annual fan energy by 50%. California is the world and the national center for development of high-level research technologies and has large numbers of research and high- technology facilities in university campuses, government buildings, and industry plants. In these research facilities, exhaust fans run 24 hours a day and 365 days a year to exhaust toxic air from the laboratories to the outside. The exhaust fans consume considerable electricity and contribute to significant amount of the electrical peak demand. This research will develop a single fan multi-stack system, which will reduce the exhaust fan annual energy significantly for both existing and new facilities.

### Proposed Outcome:

- A prototype system will be fabricated and tested.

### Anticipated Benefits:

- Potential to save on average 50% of the fan energy consumed by conventional laboratory exhausts systems.
- Retrofit payback period of only four years.

### Project Status:

- Develop a single fan multi-stack system for retrofitting the existing systems – 100%.
- Develop a single fan multi-stack system for new system design – 100%.
- First progress report due no later than 4 months after start date – 40%.

## **Distributed Generation Drivetrain for Windpower Application**

**EISG Grant Number:** 00-11

**PIER Area:** Renewables

**Principal Investigator:** Geoff Deane (805) 899-9199

**Organization:** Dehlsen Associates, LLC

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of an innovative drivetrain design for large-scale wind turbines. As wind turbines have grown, rates of revolution, limited by tip speeds on larger rotor diameters, have decreased while power has increased, increasing the torque seen by the turbines' speed-increasing gearboxes. Because of this detrimental scaling effect, for turbines growing into the megawatt range, gearboxes comprise increasing percentages of the total capital and lifetime costs, limiting the potential for reduction of energy cost. In addition, as turbine size has grown, increasing failures of the larger gearboxes have resulted in the most substantial financial loss to the industry in recent years, posing a serious concern the industry as a whole. Dehlsen Associates has developed and engineered a new gearbox concept, a novel approach to this high-torque, low rotational speed stumbling block.

This proposal outlines a project to demonstrate a 200 kW prototype Distributed Generation Drivetrain (DGD) and to develop the associated controller. The prototype is designed to eventually be installed on a wind turbine, but for the scope of this work, will be tested on a dynamometer. Detailed real-time data will be acquired during the tests to quantify dynamic behavior, efficiency, load balance, and the success of the control strategy. Results of this study will lend insight to the development of a commercial-scale DGD system.

### **Proposed Outcomes:**

- Prototype drivetrain for 200 kW wind turbine.
- Prototype controller.
- Feasibility analysis based on performance of prototype controller and drivetrain.

### **Anticipated Benefits:**

- Reduce the capital cost of installation of large wind turbines by 7%.
- Reduce lifecycle maintenance costs by 30%.
- Reduce the cost of power generation from 3.88 cents/ kWh to 3.46 cents / kWh.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Draft Final Report Completed – Under Review.
- Feasibility Analysis Completed – Under Review.

## Energy Efficient Municipal and Industrial Odor-Control Equipment Study

**EISG Grant Number:** 01-09

**PIER Area:** Industrial/ Ag/ Water

**Principal Investigator:** Bob Richardson (530) 474-4819

**Organization:** Pacific Rim Design & Development, Inc.

**Grant Amount:** \$74,982

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of a new energy efficient process for eliminating odors at wastewater treatment facilities. The proposed process reduces the amount of energy used by blowers and compressors. Consulting engineering firms across the country have been and are still specifying wet scrubbers and carbon absorbers more frequently than any other waste-water treatment and odor-control technology. Because this generation-old (30 years) technology employs large motors and is continuously operated in most facilities, it is a prime subject for energy-efficient design revision. These large energy users are necessary because the older wet scrubber technology had to move the foul air and either re-circulate large quantities of liquid, or make large volumes of compressed air for atomizing nozzles. The carbon absorbers use large quantities of energy to push the foul air through a granular material. This new technology utilizes a more effective oxidant and mixes it into the foul air stream with low-pressure nozzles.

### Proposed Outcomes:

- A pilot scale odor control plant will be installed at a Pacific Rim test site.
- Feasibility analysis based on the performance of the pilot plant.
- Procedures for safe operation of the new equipment in the waste water treatment plant environment.

### Anticipated Benefits:

- Reduce by 40% the amount of electrical energy used in odor control equipment.
- Improve odor removal efficiency over conventional equipment.
- Elimination of the large scrubber vessel saving the cost of the vessel, the cost of maintenance of the vessel and recovering the space that such large vessels occupy.

### Project Status:

- Prepare test protocol – 100%.
- Design pilot equipment – 100%.
- Procure materials and build pilot equipment – 100%.
- Procure/install instrumentation and controls – 100%.
- Start up and testing of pilot equipment – 75%.
- Test pilot odor control equipment – 20%.
- Test other odor control equipment – 0%.

## Energy Production from Bulk Wastewater

**EISG Grant Number:** 99-36

**PIER Area:** Renewables

**Principal Investigator:** Eric McFarland (805) 893-4343

**Organization:** University of California, Santa Barbara

**Grant Amount:** \$75,000

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of producing wastewater microorganisms capable of efficient biosynthesis of hydrogen gas. The most promising microorganisms will be cultured and tested in a prototype sub-scale anaerobic digester. Anaerobic digesters have no free oxygen. Anaerobes get oxygen by the decomposition of compounds containing it. The technical objective of this project is to develop a means for the efficient, economic, biosynthesis of hydrogen gas (H<sub>2</sub>) in wastewater anaerobic digesters for use as an environmentally clean fuel. Though scheduled first for automobile use, future electricity generation systems will increasingly use hydrogen if a cost-effective source of hydrogen gas becomes available. While hydrogen can be produced by reformation, decomposition, or electrolysis, these methods are relatively energy intensive or utilize non-renewable resources. An attractive alternative for H<sub>2</sub> production has been biosynthesis, however, to date the practical realization of bulk hydrogen synthesis from living organisms has not been achieved.

### Proposed Outcomes:

- Combinatorial methodology for screening microorganisms capable of optimal H<sub>2</sub> production.
- Prototype bench top digester/bioreactor.
- Feasibility analysis based on performance testing of selected microorganisms in prototype bioreactor.

### Anticipated Benefits:

- Demonstrate the effectiveness of combinatorial methodology in the screening of numerous genetically diverse mutant microorganisms for optimal H<sub>2</sub> production.
- Increase H<sub>2</sub> production from wastewater anaerobic digesters to a level that makes power generation commercially viable.

### Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – Under Review.
- Feasibility Analysis Initiated.

## **Energy-Efficient Process for Using Membrane Technology to Treat and Recycle Agricultural Drainage Water**

**EISG Grant Number:** 01-23

**PIER Area:** Industrial/ Ag/ Water

**Principal Investigator:** Ronald Enzweiler (925) 283-4918

**Organization:** WaterTech Partners

**Grant Amount:** \$74,788

**Status:** Active

### **Project Description:**

The purpose of this project is to demonstrate the feasibility of using a more energy efficient two-stage membrane process for desalinating and recycling agricultural drainage water. Substantially less energy is required to desalinate agricultural drainage using membrane technology than is required for sea water because the drainage water has substantially less salinity. Membrane technology is not presently used to treat and recycle agricultural drainage water because no viable pretreatment process exists. Agricultural drainage water is so hard (up to 2,000 mg/L of calcium and magnesium expressed as calcium carbonate) that scale quickly builds up on the surfaces of the membrane elements. This scale causes the membrane elements to foul and become unusable. Pretreatment by conventional means (e.g., ion exchange or lime/soda precipitation) and/or the use of sequestering agents as scale inhibitors has proven to be impractical or ineffectual in previous pilot tests and field trials.

The objective of this project is to perform proof-of-concept testing of a novel pretreatment process, called "preferred precipitation" nanofiltration, which has the potential to overcome to current barriers to using membrane technology to treat agricultural drainage water.

### **Proposed Outcome:**

- A two-stage device will be assembled and tested with drainage water in the project.

### **Anticipated Benefits:**

- Produce 80,000 Acre Feet/year of "new water" from agricultural drainage water in California using the two-stage membrane process.
- Restore 250,000 acres of drainage impaired farmland in the Western San Joaquin Valley.
- Reduce the cost of desalination by 25% over the most cost effective methods currently available.
- Improve the water quality flowing into the San Francisco Bay Delta.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## Evaluation of New Solar Air-Conditioning System

**EISG Grant Number:** 00-16

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Bill Kopko (703) 323-9578

**Organization:** WorkSmart Energy Enterprises, Inc.

**Grant Amount:** \$74,546

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of a solar air-conditioning system that combines a liquid desiccant-based cooler and a low-cost solar collector for regenerating the liquid desiccant. The project will build and test a bench-scale prototype for evaluating a new solar air-conditioning system. The new system combines a desiccant-based cooler and a low-cost solar collector. In addition the system provides low-cost energy storage, which allows the use of off-peak electricity for backup during extended cloudy periods. The project will involve testing heat-exchanger components, building a prototype cooler, measuring the performance of the cooler, building and testing a small solar collector, assembling and testing a complete bench-scale solar air conditioner, and summarizing the results in a final report. Successful completion of this project will obtain basic component performance data and demonstrate a working bench-scale solar air conditioning system.

### Proposed Outcomes:

- Subscale prototype system.
- Feasibility analysis based on prototype performance.

### Anticipated Benefits:

- Reduce AC power consumption by 80% compared to conventional air conditioning.
- Competitive installed costs to conventional AC systems.

### Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.



## Field Feasibility Determination of a Novel Energy-Saving Refrigeration Controller

**EISG Grant Number:** 01-12

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Patrick D. French (303) 792-5615

**Organization:** ADA Technologies, Inc.

**Grant Amount:** \$75,000

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of developing a frost sensor, microcontroller, and special algorithm to fine-tune the defrost cycle for industrial/commercial refrigerators by activating and terminating defrost cycles only when frost appears on the evaporation coil. ADA will perform a field evaluation of this novel device and determine the actual energy savings under real-world conditions. For this project, the prototype controllers will be installed in operating commercial refrigeration systems in California to quantify and document the actual energy savings and the associated improvement in temperature regulation. By determining the actual energy savings of demand defrost under real world conditions in this project, the stage will be set for cost/benefit calculations to be made.

### Proposed Outcomes:

- Prototype frost sensor microcontrollers for use in field tests.
- A model to predict energy savings.
- Modified firmware that includes additional alarm conditions.
- Feasibility analysis based on performance of prototype system.

### Anticipated Benefits:

- The proposed demand defrost system has the potential to reduce refrigerator energy consumption from 6 to 15% by reducing the number and length of defrost cycles.
- This has the potential to save .034 quads of electrical energy from commercial refrigeration in the U.S. based on the following assumptions (.6304 quads consumed in this category, 11% improved efficiency, and 50% market penetration).

### Project Status:

- Prepare Equipment for Field Testing – 100%.
- Prepare for Field Test – 100%.
- Collect, Process and Analyze Data – 50%.
- Develop Energy Savings Calculator – 0%.

## **Field Validation of a Model of Generation and Migration of Methane and Other Gases in Landfills**

**EISG Grant Number:** 00-26

**PIER Area:** Renewables

**Principal Investigator:** Richard Prosser (714) 632-9969

**Organization:** GC Environmental, Inc.

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of field testing a simulator that will allow the user to predict and monitor the behavior of landfills. The municipal solid waste (MSW) that is deposited in landfills undergoes anaerobic decomposition and produces a gaseous mixture called landfill gas (LFG), which consists mostly of methane and carbon dioxide (and some smaller amounts of oxygen and nitrogen) together with trace amounts of a number of volatile compounds (VOC). A typical landfill produces about 4-5 million standard cubic feet per day of LFG with larger landfills producing upwards of 50 million SCFD. Understanding how landfill gas is generated and migrates within landfills is of paramount importance to improve the collection efficiency of LFG without poisoning LFG generation by pulling air into the waste.

The use of LFG for generating electricity is a promising approach both in terms of conserving energy and also for reducing air pollution while producing electricity since the VOC in LFG are burned in the combustion chamber. LFG has the potential of becoming an abundant and stable renewable source of energy for California and the nation. The challenge that exists is to collect all the gas that is produced in the landfills, and not allow it to be inadvertently lost to the atmosphere as fugitive emissions. This project will help optimize landfill gas collection and utilization systems for energy production.

### **Proposed Outcomes:**

- Develop a validated simulator that can predict the rate of gas generation and migration, flow of the leachates, the composition of the gas and air on top surface of the landfill and in the surrounding soil, and the pressure build-up in the landfill.
- Help increase the understanding of dynamic subsurface behavior in relation to environmental and physical process changes.

### **Anticipated Benefits:**

- Reduce landfill gas emissions, which will decrease air pollution and increase LFG power plant generating potential.
- Increase the captured amount of useful landfill gas for power generation.
- Reduce landfill gas power plant costs by increasing efficiency.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## **Flexible Low Emissions Combustor for Renewable Fuels**

**EISG Grant Number:** 01-16

**PIER Area:** Renewables

**Principal Investigator:** John T. Kelly (408) 982-2302

**Organization:** Altex Technologies Corporation

**Grant Amount:** \$74,959

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of developing a flexible low emissions biomass combustor for renewable fuels that are poorly formed, inconsistently sized and contain high moisture. FLEC uses special features to handle inconsistently sized and high moisture wastes. In addition, an aggressive ash handling method is utilized to avoid deposition on heat transfer surfaces and passages, and positively remove ash from the system. With FLEC, nearly all plant wastes can be converted into energy at a cost that will be close to that of converting fossil fuels and will further the use of plant wastes for power generation, while helping reduce the air pollution associated with electricity generated with fossil fuels.

### **Proposed Outcomes:**

- A prototype test FLEC.
- Feasibility analysis based on performance and economic evaluation of prototype.

### **Anticipated Benefits:**

- Provide a cost effective and environmentally clean solution to converting low value biomass materials to useful electrical energy.
- Reduce the cost of biomass combustion by 30% relative to grate based and fluidized bed systems.

### **Project Status:**

- Prepare FLEC Test Combustor and Materials – 100%.
- FLEC Tests – 100%.
- FLEC Evaluation –100%.
- Feasibility Analysis Report – 0%.

## **Flywheel Energy Storage Units in Power Distribution Networks**

**EISG Grant Number:** 01-02

**PIER Area:** Energy Systems Integration

**Principal Investigator:** John Balachandra (916) 278-7347

**Organization:** ELCOM

**Grant Amount:** \$74,888

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of incorporating flywheel energy storage units into power distribution systems to maintain power quality and voltage stabilization. A 2 kW Dynamic Rotary UPS (DRUPS) flywheel system will be incorporated into a micro power distribution system with a variety of loads attached to different buses. Power quality anomalies will be introduced into the system to determine the ability of the DRUPS to maintain system integrity, reliability, efficiency, voltage stability and power quality.

The actual testing of the system would be preceded by computer simulations of the DRUPS in the system and the dynamics compared with the actual test results.

### **Proposed Outcomes:**

- Assemble a micro power distribution system with a 2 kW Flywheel Energy Storage Unit integrated into the system.
- Determine the ability of the Energy Storage unit to maintain power quality within a micro power distribution system.

### **Anticipated Benefits:**

- A capability to respond to and mitigate power distribution system voltage variations of greater than 15% plus or minus, within 150 milliseconds.
- A capability to respond to voltage perturbations on the supply side by carrying the load for a period greater than 15 seconds.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## **Gyroton Rotary Engine Project: A Controllably Variable Compression and Displacement Rotary Engine**

**EISG Grant Number:** 01-05

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Geoff Deane (805) 899-9199

**Organization:** Dehlsen Associates, LLC

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of constructing a rotary engine based on geometries that produce and follow an idealized, Asymmetric Complete-Expansion Cycle. The proposed engine design provides high thermodynamic and mechanical efficiencies, and a high power to weight ratio. Because it asymmetrically expands its working gases, the exhaust temperature and pressure are significantly lower than conventional designs, making it less acoustically and thermally obtrusive. The geometry allows dynamic control of both the engine's compression ratio and the engine's total displacement, allowing significant improvements to efficiency in various operating conditions, such as using varied fuels and operating under low engine load requirements.

### **Proposed Outcomes:**

- A 10 HP prototype engine will be constructed.
- Feasibility analysis based on the performance of the prototype engine.

### **Anticipated Benefits:**

- Increase the fuel efficiency of internal combustion engines by improving the thermodynamic and mechanical efficiencies of the engine, which are needed to make IC engines competitive in the distributed generation market.
- Make available a more efficient IC engine with a capital cost around \$400/kW.

### **Project Status:**

- Design – 50%.
- Fabrication and Assembly – 1%.
- Testing – 0%.

## High Speed Light Activated On/Off Thyristor

**EISG Grant Number:** 99-17

**PIER Area:** Energy Systems Integration

**Principal Investigator:** David Giorgi (858) 452-8787

**Organization:** OptiSwitch Technology, Inc.

**Grant Amount:** \$74,900

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of developing an all-light controlled on/off thyristor power switch. A thyristor is an electronic device that conducts electricity in one direction only. This effort leverages prior development of a light activated switch capable only of turn-on that was developed for surge protection applications. This effort will add turn-off capability to the light activated switch thereby extending its potential use into a wide range of electrical devices- such as inverters, filters, pulse-width modulators, etc.- that can benefit from smaller, lighter and more efficient high-speed power switches. Preliminary physical tests will be performed to demonstrate feasibility.

### Proposed Outcomes:

- Using 2D-simulation code, a mathematical model will be developed of the light controlled thyristor.
- Specifications for required laser light source.
- Process steps for device fabrication.

### Anticipated Benefits:

- Increase turn-off current density capability over existing thyristor switches by a factor of four to 100 A/cm<sup>2</sup> (amps per square centimeter) while maintaining a 1µs (micro-second) turn-on time.
- This technology will enable power switches to be made smaller and lighter than existing switches, which should reduce manufacturing costs.
- Light activated switches are more reliable because they are not susceptible to faulty triggering from electrical noise.

### Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Submitted.
- Feasibility Analysis Report Drafted.

## **Highly Conductive, Water Insoluble & Thermally Stable PEM from Functionalized POMs**

**EISG Grant Number:** 00-15

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Yuhong Huang (818) 727-9786

**Organization:** Chemat Technology, Inc.

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of developing a polymer membrane for a proton exchange membrane (PEM) fuel cell that is highly proton conductive, water insoluble and stable across a wide temperature range. The proposed research is to develop highly proton conductive and thermally stable inorganic electrolytes for a proton exchange membrane fuel cell based on functionalized polyoxometalates (POM) membrane. Polyoxometalate has been proven to have high temperature proton conductivity (0.17 S/cm) and much lower cost than Nafion.

Operation at low and high temperature is desirable, because it allows a variety of operating conditions to be used. Low temperature electrolytes, such as 25 to 60 °C, are suitable for portable fuel cells. High temperature electrolyte, 120 to 140 °C, is desirable for high power larger fuel cells. High temperature fuel cell reduces the impact of carbon monoxide poisoning in reformat air fuel cells and allows attainment of high power density.

Success in developing alternative, thermally-stable conducting materials could have a tremendous impact on fuel cell technology. By eliminating the hydrous component, it is anticipated that water re-circulation hardware will not be necessary and thermal management issues will be relieved, thus greatly simplifying the overall fuel cell system.

### **Proposed Outcomes:**

- Methodology for producing polymer membranes with the specified characteristics.
- Feasibility analysis based on single cell performance testing of the most promising prototype membrane. Fuel Cell Energy will conduct cell testing. Samples will be sent to JPL NASA for evaluation.

### **Anticipated Benefits:**

- Increase PEM fuel cell reliability and lifespan.
- Reduce PEM fuel cell manufacturing costs by reducing the cost of the membrane from \$500-\$1000/m<sup>2</sup> for Nafion to \$2/m<sup>2</sup> for the proposed membrane.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## High-Volume Manufacturing for Low-cost, Flexible Solar Cells

**EISG Grant Number:** 01-18

**PIER Area:** Renewables

**Principal Investigator:** Shalini Menezes (805) 497-2677

**Organization:** InterPhases Research

**Grant Amount:** \$75,000

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of developing a new flexible thin-film solar cell based on negatively doped (n) copper indium diselenide (CIS) with fewer cell components relative to the state of the art, positively-doped (p)-CIS cell. The CIS PV cells are more efficient and reliable than other thin-film technologies. The state-of-the-art technology is based on positively doped (p)-CIS rigid glass panels, fabricated with expensive, hazardous methods that are difficult to scale up for mass production. The proposed n-CIS cell will circumvent these issues. It will use fewer cell components and a simpler, cheaper manufacturing approach. The flexible n-CIS cell will be produced via electrodeposition on a metal tape for large volume manufacture. Low cost electrodeposition incorporates the environmental benefits, low temperature growth, efficient material utilization and practical deposition rates. The same laboratory-scale equipment can be used for a MW-scale plant production.

### Proposed Outcomes:

- Manufacturing methodology for deposition of n-CIS film.
- Prototype n-CIS PV cell.
- Photoelectrochemical and composition analysis.
- Efficiency and stability analysis.
- Feasibility analysis based on performance of prototype cell.

### Anticipated Benefits:

- Reduce thin film production cost from \$26/m<sup>2</sup> to about \$2/m<sup>2</sup> resulting in a 75% reduction in PV module cost.
- Eliminate the need for cadmium in the PV modules, which reduces the potential for environmental damage.

### Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.



## **IEM's Low Cost Building Performance Infrared Camera**

**EISG Grant Number:** 01-19

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Zack Mian (518) 449-5504

**Organization:** International Electronic Machines Corporation

**Grant Amount:** \$74,946

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of incorporating cost-cutting innovations in the design of an infrared camera that will reduce the retail cost from \$12,000 to less than \$2,500, thereby expanding their use in energy audits of commercial and residential structures.

Performance monitoring projects across the U.S. have documented the potential to conserve 15% to 30% of energy use through improved operation and maintenance practices. An important step towards performance monitoring is to establish the energy efficiency of the building. Energy losses can come from a number of areas: direct loss from windows/doors missing insulation in ceilings, walls or floors inadequate caulking / weather stripping or lack of duct or piping insulation.

During an energy audit, an expert performs heat loss measurements on the property among other steps. Thermal infrared imaging cameras have become an invaluable tool in performing energy audits in commercial as well as residential applications. The infrared camera has the ability to display the energy loss as an at-the-source image. This image provides an easy to use picture to assist the energy auditor. The high investment cost of an infrared camera is prohibitive to many energy contractors, and a less costly energy-loss tool with the same high-quality image properties will greatly increase their availability and use in the industry.

### **Proposed Outcomes:**

- A prototype IR camera unit.
- Field study by energy performance contractors.
- Feasibility analysis based on performance of prototype system.

### **Anticipated Benefits:**

- Potential to improve energy audits performed by energy auditors/consultants, building contractors, electrical inspectors and utility companies.
- Improved operating and maintenance practices have the potential to reduce building energy consumption by 15-30%.

### **Project Status:**

- Meeting BPCA Requirements – 85%.
- Sensor Module – 85%.
- Optics – 80%.
- On-Board Controller – 70%.
- Motion Control System – 70%.
- Main Control Module – 75%.
- Manufacturing Optimization – 65%.
- Build Prototype – 65%.
- Test Prototype Camera – 60%.

## Improved Insulation for Buildings and Refrigeration

**EISG Grant Number:** 00-33

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Jeffrey Zuker (760) 325-4003

**Organization:** Jeffrey Zuker

**Grant Amount:** \$74,525

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of using a low-cost, perlite-based ceramic insulator material to develop a thermal insulating material with high R-value for buildings and refrigeration. In the construction and refrigeration industries, insulation values are currently limited to a maximum R factor of 10 per inch. This R-value of 10 is for black Glasscell material that is rarely used. The most common materials have R-factors of from 2.5 to 8. Therefore, in order to achieve high levels of insulation, a structure must have relatively thick and expensive walls to have a high-wall, thermal insulation value.

The proposed improvement to building and refrigeration insulation is a lightweight ceramic insulation made of low-cost, readily available materials. Research shows that a ceramic insulation made with perlite and other materials can produce an insulating material with an R factor of up to 40. Perlite-based ceramic insulators have unique properties that make them suitable for building and refrigeration applications. To make the product applicable for most insulating situations, the product should be hydrophobic, should be easy to manufacture, and needs certain mechanical properties to make it marketable.

### Proposed Outcomes:

- Produce a high-efficiency ceramic thermal insulating material made from low cost materials.
- Produce a product that can be cast or molded into sheets or other desirable shapes.

### Anticipated Benefits:

- Insulation material with an R value of up to 40.
- Ceramic insulation having sufficient mechanical strength to be self-supporting and easy to handle.
- Provide leads to improving energy efficiency in buildings and refrigeration systems.

### Project Status:

- Locate and equip shop space – 90%.
- Fabricate samples – 80%.
- Conduct "In-Shop" performance tests on samples seeking high quality – Ongoing.
- Send selected samples to independent lab for R-factor testing – 0%.

## **Improved Performance of Energy Recovery Ventilators Using Advanced Porous Heat Transfer Media**

**EISG Grant Number:** 00-07

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Mark Tillack (858) 534-7897

**Organization:** University of California, San Diego

**Grant Amount:** \$74,762

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of using advanced porous media to increase the heat transfer efficiency of heat recovery ventilators to 90% (current technology is 50-80% efficient). The current trend toward sealing houses to reduce air and moisture infiltration makes them more energy efficient and reduces home energy costs. Depending on the local climate, appliance use and sealing method, tighter houses can be 15% to 30% more energy efficient. However, as homes and commercial buildings become more leak tight, adequate ventilation becomes increasingly important in order to avoid air quality problems.

If a house is constructed tighter than 0.35 air changes per hour, any pollutants generated in the home can accumulate and reduce the indoor air quality to unhealthy levels. If fresh outside air is brought in through an open window to alleviate this problem, this air may be excessively hot, cold or humidity-laden and require conditioning at added expense. Energy recovery ventilators (ERVs) use air-to-air heat exchangers to retain building heat or cooling. The heart of the system is the heat exchanger, which in some cases is used also to aid in filtration and/or humidity control. Substantial improvements in heat transfer efficiency are possible using modern low-cost gas-phase heat exchanger technology. Increasing the heat transfer effectiveness to 90% would provide a factor of 2-5 decrease in energy loss.

### **Proposed Outcomes:**

- Fabrication of porous medium samples.
- Optimized heat recovery ventilator design.
- Feasibility analysis based on performance of test samples.

### **Anticipated Benefits:**

- Provide a cost effective and energy efficient means of maintaining indoor air quality in structures that are built airtight.
- Encourage the construction of airtight houses that are 15%-30% more energy efficient.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## **Improvement of Rechargeable Li-ion Batteries Performance by Surface Modification of the Cathode**

**EISG Grant Number:** 01-21

**PIER Area:** Renewables

**Principal Investigator:** Pieter Stroeve (530) 752-8778

**Organization:** University of California, Davis

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of using lithium manganese oxide as a cathode material in rechargeable lithium ion batteries to achieve higher voltage, lower cost and increased safety. One of the main reasons for capacity fading is manganese (Mn) dissolution from the surface of the battery. Research to halt the dissolution of Mn into the electrolyte solution using polymer coatings and/or crown ether modification on molecular scale will be applied. RET will investigate if polymer coatings on the surface of the  $\text{LiMn}_2\text{O}_4$  (lithium manganese oxide) particles before cathode fabrication will lead to a hindrance of the  $\text{Mn}^{2+}$  dissolution, while still allowing adequate transport of  $\text{Li}^{+}$  (positively charged lithium ions) to the cathode material. Utilizing the property of crown ethers to trap metal ions, RET will coat the surface of the  $\text{LiMn}_2\text{O}_4$  particles with crown ethers, which can inhibit Mn dissolution. The method proposed for surface-modified  $\text{LiMn}_2\text{O}_4$  particles is feasible and can extend the lifetime of the battery by arresting the  $\text{Mn}^{2+}$  (positively charged manganese ion) dissolution, increasing the battery stability, thus the need for proof of concept testing.

### **Proposed Outcomes:**

- Produce two prototype polymer cathode coatings.
- Produce a feasibility analysis based on performance of prototype cathode coatings.

### **Anticipated Benefits:**

- Reduce the cost of energy storage in distributed power generation systems.
- Potential to contribute to grid stability and power quality by making low-cost batteries for electricity storage available.
- Potential to reduce the manufacturing cost of lithium ion batteries by 10-20%.
- Potential to reduce capacity fading in lithium ion batteries.

### **Project Status:**

- Identify electrochemical properties and surface compounds that may be chemisorbed on the surface as intermediates – 100%.
- Evaluate the surface modification of the cathode material in organic electrolyte using in situ Electrochemical Atomic Force Microscopy – 50%.

## Integral Catalytic Combustion/Fuel Reforming for Gas Turbine Cycles

**EISG Grant Number:** 99-21

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Greg Jackson (301) 405-2368

**Organization:** University of Maryland

**Grant Amount:** \$74,992

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of a novel gas turbine combustor that incorporates catalytic combustion with steam reforming of  $H_2$  that results in a stable ultra-low  $NO_x$  combustion system for high temperature gas turbines. To extend the operability/flexibility of catalytic combustors, the University of Maryland (UMCP) in collaboration with UC-Berkeley (UCB) is proposing to investigate a novel reactor concept incorporating catalytic combustion with steam reforming to provide a stable ultra-low  $NO_x$  combustion system for high firing temperature gas turbine cycles.

The reactor, which will consist of alternating catalytic combustion and reforming flow paths in a stacked configuration, will provide a unique means of avoiding overheating of the catalytic combustor. Furthermore, the reactor will also produce a secondary stream of  $H_2$  that may be used for flame stabilization in the combustor or may be sent to a fuel cell in a future combined power plant. Also, the implementation of new high-temperature hexaluminate catalysts and supports will enhance the long-term durability of the reactor and the ability of the reactor to work in higher firing temperature gas turbines. Thus, the innovative reactor concept will provide improved operability and performance of catalytic combustors through the following:

- 1) Reduced susceptibility to overheating to allow lower quality premixing and potentially higher equivalence ratios in catalytic combustors.
- 2) Potential for improved downstream flame stabilization via  $H_2$  addition.
- 3) Increased flexibility with fuel content while maintaining ultra-low  $NO_x$  emissions.

### Proposed Outcomes:

- A subscale reactor will be fabricated and tested.
- Subscale prototype reactor.
- Analysis of reactor effectiveness under high-pressure/high temperature conditions.
- Feasibility assessment based on prototype performance testing.

### Anticipated Benefits:

- Reduce gas turbine  $NO_x$  emissions to below 5 ppm.
- Improve the thermal efficiency of gas turbines by allowing the catalytic combustor to operate at higher temperatures.
- Efficient production of  $H_2$  that could be used for downstream flame stabilization or sent to a fuel cell for additional electrical generation.

### Project Status:

- 100% Completed.
- Completed behind Schedule and within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report in Process.
- Reduced Cost Power Electronic Converter for Generator Applications.

## **LEAMS (Low Emissions Atmospheric Metering Separator)**

**EISG Grant Number:** 01-07

**PIER Area:** Environmental Area

**Principal Investigator:** Doug Jung (707) 523-4585

**Organization:** Two-Phase Engineering and Research

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of a design change to reduce the noise level of the prototype LEAMS by 10-20 dB, thus resolving the main technical obstacle to commercialization. Additional design changes will be tested that will improve system performance and capacity. The separator is used for geothermal drilling, well-testing, power plant start-up and emergency venting use. The LEAMS is designed to be environmentally friendly, intrinsically safe and have multi-purpose use in the geothermal industry.

### **Proposed Outcomes:**

- Modifications to the prototype will be fabricated and installed.
- Feasibility analysis based on performance testing of modified prototype.

### **Anticipated Benefits:**

- LEAMS system has significant environmental advantages over the Blooie Muffler, which is currently used to control the emissions from geothermal well drilling.
- The Glass Mountain Geothermal Area in northern California may contain up to 500 Mw of geothermal power that cannot be recovered with existing technology due to regulatory requirements. It is anticipated that LEAMS will satisfy these regulatory requirements, making this valuable resource available to benefit California ratepayers.
- Reduces drilling and well-testing costs.
- Increases physical safety around the geothermal drill rig.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## Low Cost Hybrid Inverters Utilizing IGBTs and SCRs

**EISG Grant Number:** 00-30

**PIER Area:** Environmental Area

**Principal Investigator:** Giri Venkataramanan (608) 262-4479

**Organization:** University of Wisconsin, Madison

**Grant Amount:** \$75,000

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of developing a low-cost hybrid inverter/converter utilizing SCRs and IGBTs that could be used in variable speed drives and distributed generation systems such as photovoltaics (PV) and wind turbines. The project is aimed at reducing the cost and improving the reliability of inverters used in high power adjustable speed drives and distributed power generation systems.

Power inverters, used to convert electricity from dc to ac, constitute an enabling technology in a wide range of advanced electrical energy applications. Their application in adjustable speed motor drives continues to transform several industrial processes resulting in dramatic performance and efficiency improvements. Any reduction in inverter cost will result in broadening their application and lead to further improvements in energy efficiency. Inverters also form an integral part of modern distributed utility-grade power generation systems such as photovoltaic systems, wind energy systems, fuel cells and micro-turbine systems. These applications also stand to gain from reduced costs of inverters. The proposed inverters will realize higher reliability, lower cost and higher performance when compared to conventional pulse width modulated inverters using IGBTs or line-commutated inverters using SCRs respectively.

### Proposed Outcomes:

- Developed computer simulation based on existing models.
- Design and built circuit.
- Quantification of performance based on working design.

### Anticipated Benefits:

- May reduce converter/inverter costs by up to 75%.
- Increased reliability.
- Potential increase in performance output.
- May eliminate poor input power quality.

### Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## **Low Cost Microchannel Reformer for Hydro Production from Natural Gas**

**EISG Grant Number:** 99-14

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Darby Makel (530) 895-2771

**Organization:** Makel Engineering Inc./Darby B. Makel

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of fabricating prototype microchannel reformers for converting natural gas to hydrogen for use in fuel cells. Innovative fabrication strategies will be investigated and tested.

### **Proposed Outcomes:**

- Two prototype reformers that employ different fabrication strategies.
- Performance results from prototype tests.
- Methodology for fabricating small, low-cost, scaleable, natural gas reformers.

### **Anticipated Benefits:**

- Enable the mass production of low cost natural gas reformers, thus significantly reducing the manufacturing cost of integrated fuel cells.
- Enabling technology that would allow small residential and commercial fuel cells to operate from the abundant and inexpensive natural gas supplies in California.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Submitted.
- Feasibility Analysis Report Drafted.



## Low-Cost, High Efficiency Solar Cell Fabrication Using Inkjet Printing

**EISG Grant Number:** 01-26

**PIER Area:** Renewables

**Principal Investigator:** Neil Kaminar (408) 524-9739

**Organization:** SunPower Corporation

**Grant Amount:** \$74,948

**Status:** Active

### Project Description:

The purpose of this project is to determine the feasibility of using low-cost, high-resolution inkjet printing technology to fabricate high-efficiency solar cells. The process SunPower uses to fabricate its solar cells is unique in the solar industry. SunPower's manufacturing is more similar to processes and equipment used by the integrated circuit industry than to other solar cell companies. Achieving high cell efficiency requires patterning very fine device features, about 0.004 inch (100  $\mu\text{m}$ ) in size. Presently SunPower uses photolithographic processing to define the very fine patterns needed, but this is very costly. To make lower cost cells, lower cost equipment and processes must be found, while not sacrificing the resolution required for high efficiency.

Inkjet printing offers a possible solution. Resolution of common desktop inkjet printers, selling under \$200, are typically 720 DPI (dots per inch), equating to 35  $\mu\text{m}$  dot spacing. They are also easy to use – just load up the desired pattern and press print. Finally, they are "off contact" meaning that only the ink touches the substrate, unlike other printing techniques.

### Proposed Outcome:

- The project will modify a commercial inkjet printer and formulate special inks, which will be used to physically test the concept.

### Anticipated Benefits:

- Potential to achieve cell efficiencies of 21% without an increase in manufacturing cost.
- Potential to reduce PV module cost to \$1.92 dollars per watt by 2005.

### Project Status:

- Modify Ink – 100%.
- Modify Printer – 100%.
- Print Test – 100%.
- Feasibility Analysis Report – 0%.

## Materials for Fast-Response Solid Oxide Fuel Cells (SOFCs)

**EISG Grant Number:** 01-04

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Lutgard De Jonghe (510) 486-6138

**Organization:** University of California, Berkeley

**Grant Amount:** \$74,997

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of using a specially formulated composite anode layer on the thin ceramic electrolyte film in a SOFC. The anode layer will be low cost and tuned to the thermal expansion coefficient of the ceramic electrolyte film to permit rapid thermal cycling. Within the context of intermittently operating systems, is the capability of the fuel cells to withstand not only repeated thermal cycling, but also rapid heating as well. To date there is no satisfactory answer to reliability questions for SOFCs in intermittent distributed power scenarios. The basic problem is one of materials compatibility. The present work intends to remedy this problem by identifying and evaluating electrode materials that can support the thin film solid oxide electrolyte in the SOFC through conditions of rapid thermal cycling.

### Proposed Outcomes:

Prototype laboratory scale SOFC membranes constructed with composite anode layer.

Feasibility analysis based on characterization and performance of prototype membranes to withstand rapid thermal cycling while maintaining a high power density (300 mW/cm<sup>2</sup>).

### Anticipated Benefits:

- Increase the reliability of SOFCs used in distributed generation applications by making them capable of rapidly cycling from room temperature to an operating temperature of 850°C.
- Reduce membrane cost to less than \$65/ft<sup>2</sup>.

### Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## Method of Improving Efficiency of Combined Cycle Power Plants

**EISG Grant Number:** 00-28

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Robert Surette (323) 669-0072

**Organization:** Energy Constructs

**Grant Amount:** \$63,500

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of using an ejector-diffuser on gas turbine exhaust nozzles to reduce backpressure and provide uniform flow distribution into the heat exchangers on combined cycle power plants. Turbine exhaust backpressure is a significant source of efficiency loss in gas-turbine fired power plants. Dynamic pressure recovery in turbine exhaust nozzles is limited by the onset of flow separation at an area ratio of the order of 1.5:1. By adding an Ejector-Diffuser (Patent No. 5,632,142), the total expansion ratio can be doubled without flow separation.

Additionally, the ejector provides a source of suction that can be used to modify the boundary layer separation experienced in the transition section of the heat recovery steam generator. This will allow a much more uniform flow distribution into the heat exchangers with fewer mechanical attenuation devices such as perforated plates, which are a major source of pressure loss. The added pressure recovery will manifest itself in a reduction in turbine exhaust backpressure that directly translates into an increase in power at the same fuel consumption or lesser fuel consumption at the same power output.

### Proposed Outcomes:

- Computational Fluid Dynamics model.
- Quantify pressure recovery potential.
- Demonstrate potential for stabilizing the boundary layer in the transition layer.

### Anticipated Benefits

- Potentially increase of energy by a half of one percent.
- Easy retrofit design.
- Potential payback of 2-3 years.

### Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## Microturbine Based Building Energy System

**EISG Grant Number:** 01-14

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Nissen A. Jaffe (650) 961-1341

**Organization:** Nissen A. Jaffe

**Grant Amount:** \$68,058

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of using a variable, partial, recuperator exhaust by-pass on a natural gas fired microturbine that would allow the turbine to be used for absorption cooling, space heating and power generation in commercial buildings. A feature which distinguishes microturbines from conventional small gas turbines is the recuperator, a heat exchanger used to pre-heat combustion air with exhaust products.

The project will focus on determining the feasibility of employing the recuperator exhaust by-pass to facilitate the following waste heat applications:

- Absorption cooling.
- Space heating.
- Domestic hot water production.

An adjustable fraction of the microturbine exhaust will be diverted from the recuperator and used to produce a higher temperature waste heat stream. Absorption equipment operating off of microturbine exhaust without supplemental firing is limited to single effect systems having a nominal coefficient of performance (COP) of 0.6 raising the temperature by using a recuperator by-pass offers the potential of operating double effect absorption systems having a nominal COP of 1.2.

### Proposed Outcomes:

- System design.
- Model of building profiles for energy supply, power demand and thermal demand.
- Economic analysis of the proposed system.
- Feasibility analysis of microturbine exhaust diversion system.

### Anticipated Benefits:

- This technology seeks to optimize the energy efficiency of microturbines in commercial building applications, which could reduce their energy consumption from the grid by up to 80% by shifting the load to natural gas.
- It is projected that the proposed system could achieve a combined cycle peak efficiency of 85% with an average annual efficiency of 55%.
- Projected payback period is estimated to be between 1.8 and 3.9 years depending on the amount of waste heat that can be utilized.

### Project Status:

- Establish Feasibility of Variable Recuperator By-Pass – 100%.
- System and Building Model Development – 95%.
- System Optimization – 85%.
- System Design – 75%.
- Economic Evaluation – 50%.

## Modeling of Chemical Processes in Geothermal Reservoirs

**EISG Grant Number:** 99-25

**PIER Area:** Renewables

**Principal Investigator:** Subir Sunyal (510) 527-9876

**Organization:** GeothermEx, Inc.

**Grant Amount:** \$71,390

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of incorporating the recently developed TOUGHREACT code for chemical interactions into the existing TOUGH2 simulation model used for geothermal operations. Geothermal power in California today cannot compete with power from gas-fired plants because of geothermal's higher operations and maintenance ("O&M") cost. Geothermal energy's high O&M cost is due in part to the chemical problems related to geothermal fluids: deposition of chemical scales, corrosion, non-condensable gases, etc.

The O&M cost of geothermal electricity could be lowered if these processes could be quantitatively modeled on the computer so that optimized mitigation steps can be taken. Such modeling will also allow enhanced reservoir management and reduction of environmental impact through minimizing gas emissions by injection optimization, and allow estimation of mineral recovery from geothermal brines. Reduction of O&M cost, enhancement of reservoir management and mineral recovery are all identified as elements of "focus" in the CEC's "Geothermal RD&D Needs and Approaches." The reduction in O&M cost and enhanced reservoir management could save on the order of 0.25 cents/kWh for most projects.

GeothermEx, Inc. proposes to work in collaboration with LBNL to apply TOUGH2 and TOUGHREACT software to solve a set of practical chemical problems encountered in several typical geothermal fields in California. These problems, drawn from published industry experience, would include:

- 1) Recovery of valuable minerals (such as zinc, silver and manganese) from geothermal brines.
- 2) Scale deposition around wells.
- 3) Effects of injecting acidic brine originating from various fluid handling processes.
- 4) Minimizing gas production through optimized water injection.
- 5) Modeling of chemically reactive tracer tests to enhance reservoir management.

### Proposed Outcomes:

- Produce a comprehensive geothermal model that integrates TOUGHREACT code with the TOUGH2 model.
- Feasibility assessment based on model's ability to perform under real-world conditions.

### Anticipated Benefits:

- Reduce the cost of electricity generated by geothermal operations by .25 cents/kWh.
- Optimize mineral extraction strategies for California's high-salinity geothermal reservoirs.

**Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Submitted.
- Feasibility Analysis Report Drafted.
- Revised Final Report Draft Submitted.

## **New Generation Thermoelectric Materials for Power Generation and Refrigeration**

**EISG Grant Number:** 99-05

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Angelica Stacy (510) 642-3450

**Organization:** University of California, Berkeley

**Grant Amount:** \$74,994

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of fabricating a thermoelectric material into a layer of microscopic unidirectional wires that are oriented perpendicular to the first layer which, in theory, should improve the conversion efficiency of generating electricity directly from heat. Thermoelectric power generators are produced by joining two thermoelectric materials with opposite charge carriers and applying heat to one side. The thermoelectric fabrication be accomplished through the precise, electrodeposition of Cobalt Antimonide (CoSb<sub>3</sub>) into a porous template. The objective is to produce a higher-efficiency thermoelectric material that can be used in power generation and refrigeration.

### **Proposed Outcomes:**

- Optimized methodology for electrodeposition of CoSb<sub>3</sub> in a porous alumina template.
- Assessment of the thermoelectric properties of a fabricated array of CoSb<sub>3</sub> nanowires using electrodeposition.

### **Anticipated Benefits:**

- Improve the efficiency of thermoelectric materials above the current state of the art by 10 percent.
- The advantages of thermoelectric power generation include: no emissions, no moving parts, quiet operation, and can operate from waste heat.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Draft – Under Review.

## **Omni SmartPump**

**EISG Grant Number:** 99-12

**PIER Area:** Industrial/ Ag/ Water

**Principal Investigator:** Bernie MacDonald (707) 937-4352

**Organization:** Omni Instruments

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of using prototype, high-efficiency, variable-speed electric motors with programmable control electronics and pressure sensors to more energy efficiently provide constant optimal pressure to a closed loop drip irrigation system. The use of a standard single speed motor running at full power wastes electrical energy when it delivers either too much or too little water pressure. This project will fabricate and bench test 3-4 prototype systems in the 2 horsepower power range that incorporate variable speed AC and DC motors, digital controllers, pump heads and external sensors. One or more of the designs will be field-tested under real world conditions.

### **Proposed Outcomes:**

- Prototype variable speed irrigation pump optimized for drip irrigation applications.
- Compare the energy efficiency of prototype systems with conventional irrigation pumping systems.
- Identify the technological obstacles to scaling up large AC motors for variable speed operation for use in drip irrigation.

### **Anticipated Benefits:**

- Improve the energy efficiency and cost of drip irrigation pumping systems by eliminating the need for a separate pressure tank while maintaining a constant optimal water pressure.
- Motor control technology can be scaled up to include large AC motors used in large-scale irrigation operations.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Draft Completed.
- Final Report Revisions in Process.



## **Omni-Directional Insect Eye Concentrator Using a Hyper-Spectral Photovoltaic Cavity Converter (PVCC)**

**EISG Grant Number:** 00-13

**PIER Area:** Renewables

**Principal Investigator:** C. Wood Hays (760) 744-2575

**Organization:** United Innovations, Inc.

**Grant Amount:** \$74,992

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of a high efficiency PV system that utilizes an omni-directional insect eye concentrator (OMNICON) to direct light into a cavity that is lined with single junction solar cells that are coated such that they absorb a specific portion of the light spectrum and reflect the remainder of the spectrum to the other cells in the cavity. OMNIECON combines two new technologies, the omni-directional insect eye to eliminate tracking, and a light-confining cavity for high efficiency. In the cavity, the solar spectrum is split into several frequency bands, and a set of single junction solar cells with complementary band gaps efficiently converts matching photons into electricity. Splitting is caused by selective transmission and reflection of photons with Rugate filters on the cells. OMNIECON can reach collective efficiencies of 45% to 50%.

### **Proposed Outcomes:**

- Optimized system design that incorporates the concentrator, Rugate filters and single junction PV cells.
- Feasibility analysis based on modeling and system design.

### **Anticipated Benefits:**

- Increase PV efficiency in converting solar energy into electricity from the current level of 8 – 16% to 38%.
- Reduce the installed cost of PV from \$5 - \$6/Watt to \$1.50 - \$3.00/Watt.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – Under Review.
- Feasibility Analysis Draft Completed – Under Review.

## OTM Aided Oxygen Enhanced Combustion

**EISG Grant Number:** 00-29

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Theodore Tsotsis (213) 740-2069

**Organization:** University of Southern California

**Grant Amount:** \$75,000

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of using oxygen transport membranes (OTMs) to generate oxygen for oxygen-enhanced combustion (OEC) for flame stability and NO<sub>x</sub> reduction in power generation systems. The use of an O<sub>2</sub>-enriched oxidizer in natural gas combustion stems either from the requirement to achieve high temperatures in industrial furnaces and boilers (with either low, e.g. 21-30%, or high, e.g. 80-95%, O<sub>2</sub> -enrichments being of practical interest), or the need to enhance flame stability under fuel-lean burning conditions in gas turbines. OEC is a potential solution in the latter application, because increasing the O<sub>2</sub> content allows more stable burning, while maintaining the same flame temperature, an important consideration, since flame temperature is a good measure of the combustion device's energetic output. Furthermore, for the same flame temperature, O<sub>2</sub> -enrichment offers the additional advantage of lower NO<sub>x</sub> production due to the reduced N<sub>2</sub> content. OEC also shows promise in power generation for staged combustion with the O<sub>2</sub> -enriched oxidizer involved in one of the stages.

Other OEC beneficial effects include:

- Increased radiative heat transfer rates.
- Enhanced power output and thermal efficiency.
- Significant reduction in flue-gas volume.

OEC flue-gas contains higher CO<sub>2</sub> levels, which gives an important advantage if CO<sub>2</sub> capture/recovery ever becomes an issue. Taken together these benefits give OEC an excellent long-term potential for expanded power generation applications.

### Proposed Outcomes:

- Subscale prototype system.
- Feasibility analysis based on prototype performance.
- Better understanding of combustion process.

### Anticipated Benefits:

- Increased thermal efficiency and improved flame stability.
- Lower NO<sub>x</sub> due to lean premixing.
- Reduced flue gas volume.

### Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed - in Technical Review.
- Feasibility Analysis Report - Analysis in Progress.

## Plug-in Photovoltaic Receiver for Concentrator Applications

**EISG Grant Number:** 99-22

**PIER Area:** Renewables

**Principal Investigator:** Pierre Verlinden (408) 991-0910

**Organization:** SunPower Corporation

**Grant Amount:** \$74,977

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of fabricating a standardized plug-in photovoltaic (PV) receiver for Fresnel-lens concentrator systems. High-concentration photovoltaic systems hold the potential to dramatically reduce the cost of PV electricity. By concentrating sunlight with inexpensive plastic lenses, the required area of costly solar cells can be dramatically reduced. In addition, high-concentration PV systems are more efficient - compared to conventional flat-plate silicon photovoltaic panels, they can generate about 40% to 60% more energy per unit area on an annual basis.

SunPower Corporation will develop a standardized, highly reliable, plug-in photovoltaic receiver for high-concentration Fresnel-lens systems. The plug-in PV receiver would be factory assembled and would include the following components in a single package: a PV cell, a substrate, a secondary optical element, a bypass diode, a heat spreader and heat sink, and exterior electrical and mechanical connections. The yearly energy output per unit area of this PV concentrator system is expected to be much greater than a conventional flat-plate silicon module, significantly reducing balance of system (BOS) costs. For moderate volume production, the installed cost of this system will be about \$3000/kW, or about half of the cost of today's flat-plate PV systems.

### Proposed Outcomes:

- Up to four prototypes receiver units will be built and tested.
- Prototype plug-in PV receiver module.
- Specifications for plug-in PV receiver module.
- Process steps for device fabrication.
- Feasibility assessment based on prototype performance testing.

### Anticipated Benefits:

- Reduces the installed cost of fully integrated PV concentrator systems to about \$3,000/kW which is less than half the cost of current flat-plate PV systems.
- Increases the performance and reliability of concentrator systems by integrating into a single module, under factory controlled conditions, the PV cell, substrate, secondary optical element, bypass diode, heat spreader, heat sink and electrical and mechanical connections.

### Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Submitted.
- Feasibility Analysis Report Drafted.

## **Polymer-Zeolite Nanocomposite High-Temperature Proton-Exchange-Membranes for Fuel Cells**

**EISG Grant Number:** 00-31

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Yushan Yan (909) 787-2068

**Organization:** University of California, Riverside

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of developing a novel, polymer zeolite nanocomposite proton-exchange-membrane (PEM) to allow a PEM fuel cell to operate at high temperatures with comparable or superior performance to that of a bare Nafion PEM fuel cell operated at 80°C. Current Nafion-based PEM fuel cell systems still face significant technology roadblocks that have to be overcome before the technology can become commercially viable.

These technology roadblocks include:

- Water management at the electrodes.
- CO poisoning of the anode catalyst.
- Slow cathode kinetics.
- High cost of the electrode catalyst.

It has been demonstrated that these problems will be eliminated once the operating temperature is increased to above 100 °C.

Recently, hydrophilic silica nanoparticles have been incorporated into Nafion membrane to help maintain hydration at high temperatures with promising results. But the cell performance of these silica-containing membranes is still inferior to the bare Nafion operated at 80 °C. Although hydrophilic, silica particles are not proton conductors. Clearly, a material that is not only hydrophilic but also a good proton conductor is preferred. Zeolites are such materials. Zeolites are a class of crystalline aluminosilicates with uniform pores and cavities. First, aluminosilicate zeolites are hydrophilic. Because of zeolites' microporosity (<20 Å), zeolites can maintain hydration at very low relative humidity. Aluminosilicate zeolites are also proton conductors. Therefore zeolites are expected to be a much better material than silica for the application.

### **Proposed Outcomes:**

- Synthesized zeolite nanocrystals.
- Produce a nano-composite proton-exchange-membrane (PEM) that will operate at high temperatures (110-115° C).

### **Anticipated Benefits:**

- Increase working temperature by 30-35<sup>0</sup> C.
- Reduce problems associated with CO poisoning of the anode catalyst.
- Reduce PEM operating costs.

### **Project Status:**

- 100% Completed.
- Completed on Schedule and within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

**Proof-of-Concept of a Dual-Fired (Solar and Natural Gas) Generator for Use in a Space Cooling System for Residential and Commercial Buildings**

**EISG Grant Number:** 01-06

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Michael A Garrabrant (740) 967-3006

**Organization:** Cooling Technologies, Inc.

**Grant Amount:** \$75,000

**Status:** Active

**Project Description:**

The purpose of this project is to research the feasibility of producing a dual-fired (solar thermal and gas) generator for a 5-refrigeration ton ammonia-water absorption chiller for use in space cooling systems for residential, multi-family, and light commercial buildings. The proposed commercial system consists of a concentrated, evacuated tube solar collector and an air-cooled absorption chiller specially designed to operate on either the thermal energy generated by the solar collectors or by natural gas or propane. This system differs from previous solar powered cooling systems in that it is:

Small Size: targets the 3-25 Refrigeration Tons (RT) markets.

Air-Cooled: air-cooling does not require expensive and difficult to maintain cooling towers.

Dual-Fired: the system will be able to operate on either or both solar energy and natural gas or propane, an important feature for practical, affordable systems.

Concentrated, evacuated tube solar collectors capable of providing a 450o F supply temperature are currently commercially available. Successful completion of this project will allow solar panel manufacturers to integrate their products into a commercially available system.

**Proposed Outcomes:**

- A prototype dual-fired (solar-gas) generator for an absorption chiller.
- Feasibility analysis dual-fired design based on performance of prototype generator.

**Anticipated Benefits:**

- Reduce cooling energy cost up to 75% in a typical 2000 square foot home.
- Make available dual-fired systems in the 3-25 ton range.
- Solar thermal panels could be used for domestic hot water in the winter months when cooling is not needed.

**Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## **Prototype and Demonstration of a Light Emitting Diode (LED) Alternative to Screwbase Incandescent Lamps**

**EISG Grant Number:** 01-03

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Kathryn Conway (518) 331-7236

**Organization:** Conway & Silver, Energy Associates LLC

**Grant Amount:** \$74,850

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of constructing a light-emitting diode lamp with a conventional screwbase and color control capability that could be used in existing incandescent light fixtures. The Contractor will specify and build engineering prototypes, based on U.S. Patent 6,149,283, issued on November 21, 2000, and titled, LED Lamp with Reflector and Multicolor Adjuster.

### **Proposed Outcomes:**

- Fabricate 1 or more LED lamps as funds allow.
- A feasibility analysis based on the performance of the prototype lamps.
- Project objectives are to achieve a minimum 50% improvement in energy efficiency while maintaining light output within 20% of base case incandescent lamps.

### **Anticipated Benefit:**

- LED lamps capable of achieving energy savings of 50% to 70% in light fixtures that would normally use incandescent lamps.

### **Project Status:**

- Select lighting application for new lamp – 100%.
- Draft specifications for prototype – 100%.
- Issue bid for prototype services – 100%.
- Select contractors and build lamp – 100%.
- Develop and deliver test plan to EISG – 100%.
- Issue request for quote for test services – 100%.
- Select provider, then test the lamp – 80%.
- Analyze test results compared to baseline – 10%.

## Prototype and Demonstration of Vision-Tuned Fluorescent Lamps

**EISG Grant Number:** 01-25

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Kevin W. Houser (402) 554-3858

**Organization:** University of Nebraska, Lincoln

**Grant Amount:** \$75,000

**Status:** Active

### Project Description:

The purpose of this project is to demonstrate the feasibility of developing more energy efficient fluorescent lamps in which a greater percentage of the radiant energy is used to produce light that is optimized for human vision. A significant opportunity exists to optimize light source spectra, which will lead to better vision with the minimum expenditure of energy.

The prototype lamps will fully embrace trichromacy of human vision, with the goal of eliciting the maximum response from the opponent channels. A minimum of four different types of prototype lamps will be made, varying in the degree that they stimulate the opponent channels. Increasing the opponent channel response will be achieved by maximizing radiant energy output in the three spectral regions near 446, 533, and 610 nm while simultaneously minimizing radiant energy in other parts of the spectrum. The prototype lamps will use conventional manufacturing technologies, but will make use of novel phosphor blends designed to regulate the opponent channel responses. This work will pave the way for large scale production of energy efficient vision-tuned fluorescent lamps.

Psychophysical data will be collected during the evaluations and will be used to demonstrate that the prototype lamps are equivalent to, or exceed the performance of, conventional sources along three dimensions critically important to interior working environments:

1. Visual performance.
2. Brightness perception.
3. Color rendering.

### Proposed Outcome:

- Prototype lamps will be fabricated and tested as part of the project.

### Anticipated Benefits:

- Potential to reduce energy consumption in fluorescent lighting by 20%. Assuming 2.5 quads of electrical energy is consumed by commercial buildings nationwide, there is the potential to save .5 quads with 100% penetration.
- Potential to improve lighting quality with resulting benefits in comfort and productivity.

### Project Status:

- Make Prototype Lamps – 100%.
- Statistical Design of Testing Hypotheses – 100%.
- Physical Preparation for Demonstrations – 95%.
- Perform Demonstration and Data Collection – 80%.
- Data Analysis – 45%.

## **Quantitative Building Cooling of Tile Roofs Coated with Solar IR Reflective Coatings**

**EISG Grant Number:** 01-20

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Joseph Reilly (714) 680-6436

**Organization:** American Rooftile Coatings

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of new IR reflective coatings that can be applied to residential concrete or clay tile roofs to achieve a minimum 40% solar reflectance. American Rooftile Coatings is exploring new infrared reflecting architectural coatings for on-site application to steep-pitched concrete or clay tile roofs for the purpose of improving a home's appearance and also reducing its consumption of energy. While flat sloped roofs lend themselves to an easy switch from black to white and subsequent energy savings, steep pitched roofs are more problematic, especially regarding color choice. Aesthetically pleasing colors are important because the roof is about 50% of what one sees from the curb and darker colors are often the choice of a homeowner.

Mixed metal oxide pigments developed for the military in the 1980-s demonstrate superior infrared reflectivity. Coatings based on those pigments show improved infrared reflectance in laboratory testing. No conclusive tile roof tests have been published that demonstrate that such IR coatings substantially lower a home's temperature and energy use. American Rooftile Coatings (ARC) has taken a trademark out on 'COOLTILE IR COATINGS'™ with the hope that such coatings will lead to cooler roof temperatures and compete in the cool roof market place.

The object of this study is to quantify reductions in tile roof temperatures, building cooling power demand and energy usage that is achieved by refinishing roof tiles with IR reflective coatings. American Rooftile Coatings proposes to monitor the roof and interior temperatures of several adjacent pairs of tile-roofed model buildings. The test site will be located in an inland Southern California area to maximize the impact of the power savings in a hot, dry climate.

### **Proposed Outcomes:**

- Produce five experimental IR reflective coatings of different primary colors.
- Building energy simulation models for collecting temperature data and computing the reduction in cooling power demand and cooling energy usage by applying the IR coatings.
- Feasibility analysis based on performance of prototype coatings.

### **Anticipated Benefits:**

- Reduce the cooling load in residential homes with steep-pitch cement or clay tile roofs.
- Reduce roof deck temperature 10-20%.
- Coatings could be used on existing homes as a retrofit product, which increases the potential impact of decreased peak load cooling.



**Project Status:**

- Acquire Test Site – 100%.
- Mfg. Model Buildings – 100%.
- Mfg. Paint – 100%.
- Install Coated Tile – 100%.
- Test Tile in Lab – 100%.
- LBNL install Temperature Probes – 100%.
- LBNL Install Data Loggers & Uplink Capability – 100%.
- Initiate & Conduct Testing – 98%.

## Real Time Energy Meter Radio Frequency Communications System

**EISG Grant Number:** 01-11

**PIER Area:** Energy Systems Integration

**Principal Investigator:** Elsmore W. Bush (760) 798-2666

**Organization:** BCD Electronics, LLC.

**Grant Amount:** \$75,000

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of integrating narrowband VHF radio communications capability with selectable relay control into a DRM-2000 real time electric meter that will collect, record, and transfer electric meter data to a central location. Real Time Energy Meters (RTEM) allow utilities to establish an hourly rate structure that discourages usage during more expensive peak usage periods. Leveling peak usage reduces the need for less environmentally friendly generators. It can also provide significant savings to the residential customers.

Expected advantages of the adaptable narrowband VHF over UHF system include the following:

- Under isotropic conditions the VHF has a six-to-one free space range advantage.
- Improved structure penetration.
- Improved terrain following that will result in better coverage and less shadowing.
- Lower parts count insures increased MTBF (mean time before failure).
- Lower cost for parts operating at a six to one lower RF frequency.
- The selectable relay control will improve data acquisition reliability.
- Data acquisition time will be reduced as the result of relaying data only where direct data transfers are not possible.
- Improved thru-put by changing relay positions when marginal or varying conditions are encountered.

### Proposed Outcomes:

- A prototype real time electric meter with RF communications capability.
- A meter firmware program that incorporates the relay option and avoids energy measurement interrupts during the meter selection interrogations.
- Central control system with RF communications capability.
- Feasibility analysis based on performance of prototype system.

### Anticipated Benefits:

- Proposed system offers the potential for low cost and reliable real time metering for residential and commercial electrical consumers. This will reduce the cost of meter reading and allow for real time pricing incentives that will encourage load shifting from peak to off peak.
- Potential to have a real time electronic meter that is cost competitive to the current electro-mechanical meter that sells for \$40.
- Potential to provide electric consumers with real time electrical consumption data that would enable them to manage there power consumption more effectively.

**Project Status:**

- Printed circuit board layout and fabrication – 100%.
- Order and receive parts – 100%.
- Assemble a meter and bench test the unit – 90%.
- Check output power and receiver sensitivity – 80%.
- Modify meter firmware – 30%.
- Modify base station software – 20%.

## Reduced Cost Power Electronic Converter for Generator Applications

**EISG Grant Number:** 99-23

**PIER Area:** Industrial/ Ag/ Water

**Principal Investigator:** Herbert Hess (208) 885-4341

**Organization:** University of Idaho

**Grant Amount:** \$74,977

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of developing a more efficient and lower cost power electronic converter for use in variable speed electrical generation applications such as wind and water turbines or gas microturbines. The following three innovative, concurrent changes from the conventional method of generating with any variable-speed, turbine-generator system, like a wind-turbine generator, are proposed:

Reduce the number of power switching devices by half.

Develop a new modulation algorithm that takes advantage of common, but usually neglected filtering properties of the induction machine.

Configure a simple filter topology to capture the energy produced by the system.

The modified system has the following advantages over the conventional means of variable-speed, wind turbine induction motor systems:

- Approximately half the capital cost of the power electronic converter.
- Retains the advantages of variable speed operation without modification to the generator itself.
- Energy savings come from reduced line losses and improved ability to operate the load nearer its optimum power output and efficiency.
- Improved system performance, particularly in the case of generating behind long radial lines, with a controllable source of both real and reactive power having very low harmonic content to enhance clean, stable operation, usable as is for variable speed conversion capability for any turbine generator, such as hydro, gas microturbines, etc.

### Proposed Outcomes:

- A prototype converter will be fabricated and tested.
- Prototype power converter rated for 15 horsepower.
- Control algorithm for the direct-current bus.
- Feasibility assessment based on prototype performance testing.

### Anticipated Benefits:

- Reduce by 50% the capital cost of power electronic converters for variable speed applications.
- Enables turbines to operate at their optimum power output and efficiency.
- Saves energy by reducing line losses.
- Eliminates need to modify the generator for variable speed operation.

### Project Status:

- 100% Completed.
- Completed behind Schedule.
- Completed within Budget.
- Final Report Draft Being Refined.

## Research Energy Efficient Designs for Swimming Pool Pump Systems

**EISG Grant Number:** 00-08

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Taghi Alereza (916) 363-8383

**Organization:** ADM Associates, Inc.

**Grant Amount:** \$74,691

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of reducing the flow rate of the filter pumps on commercial and educational swimming pools while maintaining the required water quality. In educational and commercial facilities with swimming pools, it is often standard practice to run the pumps for the pool filtration system continuously at the design flow rate. Although engineering calculations show that it is reasonable to reduce the flow rate for a pool filtration system below the design flow rate, an important barrier to making this energy saving change is a concern about water quality and health problems. Health standards generally require that a minimum flow rate be maintained for public pools.

Filtering slowly makes for better filtering. However, it has been standard practice to design the filtration system for an educational or commercial facility with a swimming pool with a single pump that runs continuously at the design flow rate. Because swimming pools in educational and commercial facilities are generally not open 24 hours a day, there is room to reduce the flow rate of the filtration system pump during those hours when the pool is not in use. The question at issue is how much the flow rate can be reduced during hours when the pool is not actually being used without compromising the water quality needed for health reasons. Various aspects of water quality will be monitored, including the following:

- Turbidity or clarity of the water.
- pH level (which needs to be maintained between 7.2 and 8.0).
- Free chlorine residuals.
- Bacteriological quality of the water.
- Chemical quality of the water.

### Proposed Outcomes:

- Optimized energy efficient strategy for operating swimming pool filter pumps.
- Feasibility analysis based on performance of modified pump operation at test sites.

### Anticipated Benefits:

- Estimated energy savings of 20,000 kWh per year per pool based on a 25% deduction in flow rate for 8 hours per day.
- Potential to save 840 MWh per year in CA from approximately 40,000 candidate pools.

### Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Draft Final Report Submitted – Under Review.
- Feasibility Analysis Initiated.

## Research on Manufacturing Quadruple-Junction Solar Cells

**EISG Grant Number:** 00-14

**PIER Area:** Renewables

**Principal Investigator:** Robert Hicks (310) 825-8891

**Organization:** University of California, Los Angeles

**Grant Amount:** \$74,268

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of increasing the conversion efficiency of quadruple-junction solar cells by optimizing the chemical vapor deposition process. Quadruple-junction solar cells show great potential for achieving terrestrial conversion efficiencies above 40%. At these levels, the photovoltaic devices could be competitive for large-scale electric power generation. Quadruple-junction solar cells consist of epitaxial thin films of indium, gallium phosphide (In<sub>0.48</sub>Ga<sub>0.52</sub>P), gallium arsenide and indium gallium arsenic nitride (In<sub>0.09</sub>Ga<sub>0.91</sub>As<sub>0.97</sub>N<sub>0.03</sub>) lattice-matched to germanium substrates. A sophisticated chemical process known as metalorganic chemical vapor deposition (MOCVD) produces these materials.

The objective of this project is to identify the MOCVD process conditions crucial to the development of a robust manufacturing technology. This technology must be capable of producing defect-free films with sharp interfaces and precise composition profiles. The atomic and microscopic structures produced by MOCVD will be characterized by scanning tunneling microscopy, x-ray photoemission, spectroscopy, high-resolution x-ray diffraction, photoluminescence, and current-voltage measurements. New deposition process will be developed and examined for the fabrication of quadruple-junction solar cells with light conversion efficiencies exceeding 40 percent.

### Proposed Outcomes:

- Methodology for vapor deposition process that yields precise smooth layers with sharp interfaces between layers.
- Feasibility analysis based on performance of fabricated test samples.

### Anticipated Benefits:

- Solar power production at a cost of \$.03-\$.04 kWh.
- Achieve solar cell conversion efficiency over 40%.

### Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## Simple and Reliable Active Power Filter for Energy Efficiency and Power Quality

**EISG Grant Number:** 00-27

**PIER Area:** Environmental Area

**Principal Investigator:** Keyue Smedley (949) 824-6710

**Organization:** University of California, Irvine

**Grant Amount:** \$75,000

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of developing a fast, active power filter capable of responding within one-cycle of the frequency to cancel the harmonic and reactive current generated by the nonlinear loads of electrical transmission systems and to ensure a clean sinusoidal current draw from the power line. The utility grid provides sinusoidal voltage for a variety of users. Most of the loads in industry, commercial, agriculture, and residential applications are electronic appliances and motor drive systems, which draw capacitive and inductive currents from the grid. These loads are highly nonlinear and they inject harmonic and reactive current to the grid, resulting in low power factor, low transmission efficiency, and harmful disturbance to other appliances. One-cycle control eliminates the multipliers, the current reference calculator, and voltage sensors, which are required in the control loop of prior systems. The design requires fewer components resulting in lower cost while maintaining performance and reliability.

### Proposed Outcomes:

- Develop functional prototype.
- Develop design guidelines.
- Feasibility assessment based on prototype performance testing.

### Anticipated Benefits:

- Improve power transmission efficiency by 30%.
- Improve power quality (current distortion  $<5\%$  THD – total harmonic distortion).
- Increase reliability.
- Reduce system costs due to simplified design.
- Help eliminate harmful line disturbances that can damage appliances.

### Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## Single Crystal Silicon Sheet Growth

**EISG Grant Number:** 00-02

**PIER Area:** Renewables

**Principal Investigator:** Carl Bleil (248) 370-3406

**Organization:** Energy Materials Research

**Grant Amount:** \$75,000

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of producing single crystal sheets of semiconductor quality silicon directly from a polycrystalline source at a minimum production rate of 35 cm/min up to maximum of 350 cm/min using an advanced Horizontal Ribbon Growth (HRG) method. The patented approach presented here and validated in the laboratory addresses the critical control features of a modified HRG process necessary to realize the continuous growth of single crystal silicon sheets. A unique concept invoking capacitive coupling of RF power to the silicon sheet seed is employed. When properly applied in a uniform thermal environment, it allows disturbances at the nucleating tip and at the exit solid-liquid phase boundary to be eliminated. The problems of maintaining a uniform thermal environment, controlling temperature gradients, and preventing polycrystalline nucleation are resolved. The process permits the stable growth of the silicon sheet to be controlled electrically, making the HRG method a practical process.

### Proposed Outcomes:

- Prototype Horizontal Ribbon Growth processor.
- Production methodology.
- Technical and economic feasibility analysis of proposed methodology.

### Anticipated Benefits:

- 50% reduction in the energy consumed to produce quality silicon sheet.
- 40% reduction in the material losses associated with producing single crystal sheets.
- Potential 50% capital cost reduction of electronic grade silicon sheets.

### Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.



## **Solar Fired, Compressor Assisted Absorption Chiller**

**EISG Grant Number:** 99-15

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Jim Bergquam (916) 383-9425

**Organization:** Bergquam Energy Systems

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of improving the performance and reducing the cost of solar heated absorption chillers by incorporating a small vapor compressor into the design. Candidate vapor compressors will be identified and tested. This project targets small-to medium-sized commercial buildings with cooling loads up to 100 tons.

### **Proposed Outcomes:**

- An improved design for single and double effect solar heated absorption chillers that will reduce their operating temperatures below 140 degrees F and 250 degrees F respectively.
- Identify off-the-shelf compressors or specifications for a custom compressor that will perform the required function.

### **Anticipated Benefits:**

- Reduce the cost of the systems by eliminating the need for high pressure components that are required for systems operating above 250 degrees F.
- Reduce system payback period from 8 years to less than 5 years.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft – Submitted.
- Feasibility Analysis Report – Drafted.
- Final Report Revisions – In Process.

## **Solid State Electrolyte for Dye-Sensitized Solar Cells (DSSCs)**

**EISG Grant Number:** 01-24

**PIER Area:** Renewables

**Principal Investigator:** Russell Gaudiana (978) 654-6961

**Organization:** Konarka Technologies, Inc.

**Grant Amount:** \$74,735

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of using a specially formulated gel as an electrolyte in dye-sensitized solar cells (DSSCs) that permits effective encapsulation in the manufacturing process. Our specific project goal is to develop a solid-state electrolyte that outperforms the liquid electrolytes presently used for DSSCs, and would represent a significant advance. KTI's proposed research has three key objectives:

1. Develop an electrolyte gel that can be transitioned from liquid to solid at temperatures ranging from 40-90°C, without compromising its performance.
2. Eliminate volatiles from the coating solvents and active components.
3. Achieve cell performance equal to or better than that of liquid electrolytes.

### **Proposed Outcome:**

- Prototype solar cells will be fabricated and tested as part of the project.

### **Anticipated Benefits:**

- Potential to reduce the manufacturing cost of solar cells to less than \$1/Wp through low cost materials and roll-to-roll manufacturing.
- Low cost thin film PV would significantly expand the cost effective applications for PV in California.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## **Spectrally Enhanced Incandescent Ceramic Incandescent Emitter**

**EISG Grant Number:** 01-17

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Devon R. McIntosh (301) 283-6250

**Organization:** Sonsight Inc.

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of a new type of composite ceramic oxide emitter for an incandescent light bulb that is 300% more energy efficient than conventional incandescent bulbs and produces light that is closer to the natural sunlight spectrum with an expected color rendering that is superior to other general lighting sources. Its optical scattering and spectral absorptivity are designed to produce a spectral distribution that is much greater within the visible spectrum.

The innovation is based on:

- Utilizing a novel heating arrangement to attain high, stable incandescent temperatures.
- Optically and physically structuring a composite ceramic oxide emitter such that when heated as designed, it emits, within the visible spectrum, a much larger portion of its total radiated power than that emitted by state-of-the-art incandescent bulbs.

### **Proposed Outcomes:**

- Produce a prototype of new ceramic incandescent emitter.
- Produce a thermal model, which includes internal optical scattering.
- Provide a feasibility analysis based on performance of prototype emitter.

### **Anticipated Benefits:**

- Potential to increase the energy efficiency of incandescent light bulbs by 300%.
- Eliminate the need for mercury that is used in fluorescent and HID lamps and is becoming a growing environmental problem.
- Health and performance benefits that derive from using full-spectrum lighting.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## **SunGuard Roofing Tile for Natural Cooling**

**EISG Grant Number:** 99-07

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Thomas Dinwoodie (510) 540-0550

**Organization:** Powerlight Corporation

**Grant Amount:** \$74,885

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of an innovative residential roofing tile that will significantly reduce roof deck temperatures through passive convection and reflective means. Computer modeling and simulations will be performed and roof tile prototypes will be fabricated and tested.

### **Proposed Outcomes:**

- Optimized roof tile design that possesses the desired conduction, radiation and convection heat transfer properties.
- Prototype roof tile capable of maintaining roof deck temperature at or below ambient temperature.

### **Anticipated Benefits:**

- Projected annual energy savings of \$24-\$490 for a 2,000 sq-ft home depending on home construction and location.
- May permit the sealing of attic spaces in locations with high humidity for better moisture control.
- Tile design may be integrated with PV for added energy savings.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Submitted.
- Feasibility Analysis Report Drafted.
- Revised Final Report Draft Submitted.
- EISG Program Administrator is in the process of finalizing the Feasibility Analysis Report for publication.

## Test Program for High Efficiency Turbine Diffuser

**EISG Grant Number:** 01-29

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Thomas Norris (415) 391-2158

**Organization:** Consultants in Engineering Acoustics

**Grant Amount:** \$74,220

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of reducing backpressure on turbines designed with a right angle bend in the outlet by inserting aerodynamic vanes and devices placed inside the exhaust diffuser. The project will demonstrate the viability of a concept previously developed on a small-scale model of a power generation combustion turbine. The application is for gas turbines that have a right angle bend in the exhaust just downstream of the exhaust diffuser. The exhaust diffuser is an aerodynamically shaped duct section located just downstream of the last turbine wheel. An excellent diffuser will improve power and efficiency. The goal is to increase combustion turbine efficiency and power by one percent in most turbines with a right angle bend and by two percent in an older turbine model that is now being remanufactured and installed for peaking purposes. Fuel use is not increased.

### Proposed Outcome:

- A larger turbine exhaust scale model and fan system to replace the present 1/8-size model will be fabricated and tested as part of the project. The expected scale factor is 1/4 to 1/3.

### Anticipated Benefits:

- Potential to increase gas turbine efficiency by 1% at little additional cost thereby reducing the cost of power from gas turbines.
- Large potential retrofit market for turbines installations with right angle bends after the exhaust diffuser.

### Project Status:

- Build Scale Model – 50%.
- Install Flow Measurement Instruments – 70%.
- Build and install Flow Improvement Devices – 20%.
- Obtain Flow/Pressure Measurements – 0%.

## **The Sagebien Project**

**EISG Grant Number:** 00-24

**PIER Area:** Renewables

**Principal Investigator:** Richard Ely (530) 753-0562

**Organization:** Davis Hydro

**Grant Amount:** \$75,000

**Status:** Active

### **Project Description:**

The purpose of this project is to research the feasibility of developing an undershoot water wheel modified to allow for fish passage. Turbines and their associated diversion dams form direct barriers to fish migration up and down stream causing mortality and morbidity of species that pass them. Common low head diversion dams are open channel flows. Water wheels allow fish to pass effortlessly down stream, but challenge fish moving upstream except during floods. One type of water wheel, the undershot breast wheel – and the Sagebien Wheel in particular – might be modified to allow fish to pass both ways and still efficiently generate hydropower.

### **Proposed Outcomes:**

- Functional prototype of a modified water wheel to allow for fish passage.
- Demonstrate that a useful amount of power can be generated from the given design.

### **Anticipated Benefits:**

- Fish friendly hydropower plant allowing upstream and downstream fish passage.
- Easy adaptability to changing conditions.
- Efficient power extraction.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed – in Technical Review.
- Feasibility Analysis Report – Analysis in Progress.

## The Use of Solid Oxide Membranes in Power Generation Applications

**EISG Grant Number:** 99-32

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Theodore Tsotsis (213) 740-2069

**Organization:** University of Southern California

**Grant Amount:** \$75,000

**Status:** Active

### Project Description:

The purpose of this project is to evaluate the technical feasibility of using the waste heat in the exhaust stacks of power generating equipment to decompose CO<sub>2</sub> through the use of solid oxide membranes and to then mix the decomposed elements (CO and O<sub>2</sub>) into the fuel stream to augment combustion thereby increasing thermal efficiency. The key objective of the proposed work is to evaluate technical feasibility, environmental implications, and long-term economic viability of a novel technology that improves electric power generation efficiency while simultaneously providing an avenue for CO<sub>2</sub> sequestration.

The technology combines direct thermal CO<sub>2</sub> decomposition with an advanced power generation concept involving waste heat utilization and integration by chemical recuperation, otherwise known as the CRGT cycle. More specifically, a high-temperature, asymmetric, solid-oxide membrane reactor technology will be developed that will allow for the direct thermal CO<sub>2</sub> decomposition into CO and O<sub>2</sub>, while simultaneously utilizing waste heat in the context of power generation. The feasibility study will first focus on the choice and testing of the appropriate membrane material. Subsequently, the combustion characteristics of the resulting fuel blends of CH<sub>4</sub>/CO/CO<sub>2</sub>/O<sub>2</sub>/N<sub>2</sub>, will be systematically quantified since their combustion characteristics have not been studied systematically in the past.

### Proposed Outcomes:

- Membrane technology that will be appropriate for the direct thermal decomposition of CO<sub>2</sub>.
- Quantification of the combustion characteristics of fuel blends of CH<sub>4</sub>/CO/CO<sub>2</sub>/O<sub>2</sub>/N<sub>2</sub>.
- Feasibility assessment based on the prototype membrane and combustion testing.

### Anticipated Benefits:

- Reduce the cost of power generation in systems that utilize combustion by using the waste heat to improve thermal efficiency or by selling the decomposed elements (CO and O<sub>2</sub>) to partially offset the cost of generation.
- Reduce CO<sub>2</sub> emissions and would enable CO<sub>2</sub> sequestration if desired.

### Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Drafted.
- Reports are under review by the PA.

## Two-Phase Flow Turbine for Co-Generation

**EISG Grant Number:** 99-33

**PIER Area:** Renewables

**Principal Investigator:** Gracio Fabris (818) 952-0217

**Organization:** FAS Engineering, Inc.

**Grant Amount:** \$75,000

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of a new design for a two-phase flow turbine capable of operating at higher thermal efficiencies in geothermal power generation applications. Use of two-phase turbines (hot water plus steam) in small size cogeneration has substantial advantage over gas turbine cogeneration. The reason is that in the Brayton cycle case the compressor uses up over 70% of mechanical power delivered by the gas turbine. When steam is used, the compression power is only a few percentage points of the two-phase turbine power output. Various market applications are already mentioned. Early implementation could be to retrofit topping part of the existing, both, flash and binary type geothermal power plants. Small size early applications for waste heat utilization and cogeneration involving water and spaced heating are attractive as well. Efficiencies and economics obtainable using this device and its thermal cycles (topping flash retrofits, cogeneration, trilateral, heat pumps and others) are favorable.

### Proposed Outcomes:

- 30 kW subscale prototype turbine.
- Measure efficiency values.
- Feasibility assessment based on prototype performance testing.

### Anticipated Benefits:

- Increases turbine thermal efficiency by 20% - 40% in binary and flash type geothermal applications.
- Potential to increase efficiency in solar and thermal waste heat applications.
- Design is scalable to both small and large turbine applications.

### Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Draft Completed.
- Feasibility Analysis Report Drafted.
- Reports are under review by the PA.



## Ultra Reduced Emissions Burner for GTCC and CHP Applications

**EISG Grant Number:** 01-15

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** John T. Kelly (408) 982-2302

**Organization:** Altex Technologies Corporation

**Grant Amount:** \$74,933

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of a duct burner design for gas turbine, combined-cycle systems that can divide the flame into several zones thereby allowing better control of flame stability, CO emissions and NO<sub>x</sub> emissions. Altex Technologies Corporation has identified a duct burner concept, called the Ultra Reduced Emissions Burner (UREB), which can produce stable flames and very low NO<sub>x</sub> emissions. This can be accomplished because the burner divides the flame into several zones that are able to balance the usually conflicting requirements of flame stability, flame quality, CO and NO<sub>x</sub> emissions. Conventional duct burners using a single flame zone makes it impossible to optimize all of the flame qualities mentioned. Preliminary calculations and tests suggest that the fully-developed UREB may be able to lower NO<sub>x</sub> to 1ppm at 15% O<sub>2</sub>.

### Proposed Outcomes:

- A prototype duct burner that achieves 2ppm NO<sub>x</sub> and 6ppm CO at 15% O<sub>2</sub>.
- Feasibility analysis based on performance of prototype system and economic evaluation.

### Anticipated Benefits:

- Potential to reduce the cost of power from gas turbine combined cycle systems by reducing or eliminating the need for expensive post combustion NO<sub>x</sub> controls.
- Potential to reduce the cost of NO<sub>x</sub> removal by 90% relative to Selective Catalytic Reduction (SCR) technology.
- Estimate potential savings of \$29 Mil/year from GTCCs and an additional \$63 Mil/year if used in combined heat and power (CHP) system.

### Project Status:

- Fabricate Ultra Reduced Emissions Burner (UREB) Test Burner and System – 47%.
- UREB Tests – 0%.
- UREB Evaluation – 0%.

## Use of Waste Fuel Gas to Reduce Biofouling of Power Plant Cooling Water Intakes

**EISG Grant Number:** 01-08

**PIER Area:** Environmental Area

**Principal Investigator:** Greg Rau (925) 423-7990

**Organization:** University of California, Santa Cruz

**Grant Amount:** \$74,814

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of injecting a small amount of flue gas from a gas-fired power plant in the cooling water intake to serve as an anti-biofouling agent for the power plant cooling water intake surfaces. The colonization of cooling water intakes by biota significantly impedes water flow, increases parasitic power requirement for pumping such water, and reduces cooling efficiency when biota become lodged in condenser tubing. The present prevention/remediation of this problem includes the periodic addition of bleach to the intake water, closed-cycle heating of the water, and plant shutdown to facilitate intake drainage and physical removal of biota from intake surfaces. Various other chemical additives and pipe coatings are being used in the power industry, but these are usually expensive, have limited lifetimes, and can have environmental impacts.

Significant reductions in the growth rate of marine biota of the type that contribute significantly to biofouling are achieved by an increase in the concentration of a certain, otherwise innocuous seawater constituent. Since one source of this constituent is contained in flue gas from energy generation, it is suggested that the continuous addition of a small fraction of this byproduct into intake water could significantly reduce settling and growth of such organisms. If effective, such procedures would reduce or possibly eliminate the costly and potentially hazardous biofouling treatments currently employed. A series of on-site tests will be conducted at the Duke Energy's power plant at Moss Landing, California to determine the efficacy of such an approach.

### Proposed Outcomes:

- A laboratory scale test rig will be constructed on site.
- Feasibility analysis based on the performance of the laboratory scale system.
- Optimized strategy for delivery and dosing levels.

### Anticipated Benefits:

- Replace the costly and environmentally harmful biofouling treatments currently employed with the proposed system that would be lower cost and less harmful to the environment.
- An anti-biofouling agent that meets or exceeds all water quality regulations.

### Project Status:

- Design experimental setup – 100%.
- Construct experimental setup – 100%.
- Record experimental data – 90%.
- Analyze results – 30%.

## Ventilation Cooling Controller Strategies

**EISG Grant Number:** 99-28

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Murray Milne (310) 454-7328

**Organization:** University of California, Los Angeles

**Grant Amount:** \$74,895

**Status:** Active

### Project Description:

The purpose of this project is to research the feasibility of developing an intelligent, natural-ventilation cooling controller that can determine and implement the most efficient strategy for pulling in outside air to reduce air conditioning costs in residential homes that will minimize air conditioning costs for homeowners. The greatest potential source of cooling energy in most California climates is when cool outdoor air is available to flush overheated buildings. In most California climate zones nighttime temperatures are usually quite comfortable. The controller's task is to know how much night-time air should be brought in to cool down the building's interior mass so that it can 'coast' comfortably through the next day, and not overcool so that heating is needed the following morning. This controller should also know if it is using more fan energy then it is recovering in cooling, or if wind-driven natural ventilation is available. Our studies have shown that the need for air conditioning can often be completely eliminated in many climates if the building is carefully designed and if a smart controller can be developed to harvest this resource.

### Proposed Outcomes:

- Prototype ventilation cooling controller with control logic designed for the 16 climate zones in California.
- Feasibility assessment based on prototype performance testing performed in large-scale test cells.

### Anticipated Benefits:

- Eliminate or reduce the need for air conditioning in CA climate zones that have cool nighttime temperatures.
- Achieve minimum energy savings of 100,000 MWh per year in CA if it eliminated the need for one air conditioner per 1000.

### Project Status:

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Draft Final Report Submitted.
- Feasibility Analysis Report Drafted.
- EISG Program Administrator's Review of Final Report Draft in Process.

## **EISG Projects Completed in 2003**

## Biomass Boundary Layer Turbine Power System

**EISG Grant Number:** 00-06

**PIER Area:** Renewables

**Principal Investigator:** Darren Schmidt (701) 777-5120

**Organization:** EnergySchmidt

**Grant Amount:** \$75,000

**Status:** Completed

### Project Description:

This project explored the potential for cost effective electricity production from biomass in distributed generation applications. The focus was on the means of energy extraction from the high-energy flue gasses resulting from biomass combustion. Sufficiently energetic flue gasses from biomass combustion contain ash and other particulates that could hinder the operation of most high temperature machinery.

The researcher tested a turbine with a rotor that consists of many parallel disks. He measured its performance while firing biomass fuel. This turbine, called a “boundary layer turbine,” relies on the friction of the gases passing through the rotor to impart motion to the shaft. The technology is well known for its resistance to erosion in viscous pumping applications.

The proposed turbine was not completed and made available in accordance with the project’s schedule, however, a manufacturer, at no cost, supplied a low-efficiency turbine to the project. A used pressurized combustor was purchased and adapted to a pressurized combustion residence chamber. Over 40 hours of testing at various operating states was accomplished at very low research cost. At the conclusion of this test series, the researcher concluded that no significant barriers exist within the boundary layer turbine to hamper the use of biomass fuels.

### Proposed Outcomes:

The goal of this project was to determine the feasibility of operating a boundary layer turbine on flue gasses of a biomass combustor. The following project objectives were established:

1. Demonstrate the performance of a boundary layer turbine operating on combustion flue gas.
2. Optimize turbine performance, achieve 21 % conversion efficiency.
3. Achieve low levels of deposition, corrosion, and erosion of the turbine.
4. Design the next generation boundary layer turbine.

### Actual Outcomes:

Testing of a turbine proved that it did run on biomass fuel with the following performance.

1. Boundary layer turbine performance for five operational scenarios is tabulated here.

| Case | Working fluid/fuel   | Firing rate    | Temperature | Pressure | RPM  | Power   | Isentropic efficiency |
|------|----------------------|----------------|-------------|----------|------|---------|-----------------------|
| 1    | Compressed air       | N/a            | Unk         | 86 psig  | 8193 | 11.6 HP | Unk                   |
| 2    | Compressed air       | N/a            | 69 °F       | 33 psig  | 1100 | 0.6 HP  | 16%                   |
| 3    | Natural gas flue gas | 173,000 Btu/hr | 832 °F      | 35 psig  | 6218 | 4.6 HP  | 12.25 %               |
| 4    | Biomass flue gas     | 192,600 Btu/hr | 737 °F      | 40 psig  | 6284 | 4.3 HP  | 11 %                  |
| *5   | Saturated Steam      | Unk            | N/a         | 100 psig | 6500 | 12.4 HP | 13.7 %                |

2. Conditions were varied to determine optimum turbine operating conditions. The highest efficiencies were obtained at the highest operating speeds. Under hot operating conditions (800°F) and less than 50 psig, efficiencies of 12% were obtained. The highest rotational speed under these conditions was 6500 rpm. The efficiency and horsepower curve are linear with speed, suggesting that higher efficiencies could be obtained. Increasing pressure increased power and efficiency. Increased temperatures had the same effect but to a lesser degree. The highest torques (100 in- lbs) were obtained at the lowest rotational speeds. The turbine was equipped with two nozzles. Primarily only one nozzle was used during testing. Experiments with the second nozzle resulted in little improvement in power or efficiency.
3. Qualitative assessment of deposition, erosion, and corrosion are as follows. 150 lbs of biomass was fired in the turbine with an average ash content of 1%. The biomass consisted of wood-derived sawdust and oats, fired separately. Firing of 100% biomass was achieved. Post inspection of the turbine rotor provided no indication of ash deposits, plugging between disks, or excessive build up in the turbine housing.
4. Evaluation of power cycles was completed to arrive at a design for the next generation biomass boundary layer turbine. This preliminary design is specified in the form of a process flow diagram.

**Conclusions:**

1. This project proved that it is feasible to drive a boundary layer turbine with flue gases from biomass combustion.
2. The efficiency obtained was not as high as projected in the proposal, but the turbine used was not the one planned in the proposal. This was because when the time came to use it, the proposed turbine was not ready. Documentation of more efficient boundary layer turbines is provided. The conclusion is that higher efficiencies might be obtained with proper design of the turbine and the matching combustor.
3. No indication of ash deposits, plugging between disks, or excessive build up in the turbine housing was observed on posttest teardown. This is positive indication that this simple turbine architecture is tolerant of particulate matter in the working fluid. It seems obvious that partially burned pieces of biomass must not be fed into the turbine, but tolerance of fly ash can be a very useful characteristic.
4. Engineering calculations indicate that the achievable system efficiency may be as high as 25% with a boundary layer turbine. This will require an isentropic efficiency of 60% for the turbine. While this efficiency is theoretically achievable, only 49% efficiency has been achieved/reported in practice.

**Benefits to California:**

The benefits to California from this technology are derived from the simplicity of the system, and its potential to be transported to the source of the biomass. The challenge with forest slash and other forest biomass is its location. Transportation of the fuel to the power generator makes the fuel very expensive due to transportation costs. By transporting the power generator to the forest, the biomass fuel can be used to generate electricity. Then the problem is to transport the electricity to the consumer by attaching the generator to the grid. The added cost of grid interconnection equipment was not estimated in this project but could be high relative to the cost of the turbine.

**Recommendations:**

This project was proposed and funded with a targeted 21% isentropic efficiency. The efficiency achieved was 11% to 13%. The turbine efficiency must be approximately 50% or better in order for this technology to compete with established systems.

**Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

## Catalytic Stabilizer for Industrial Gas Turbines

**EISG Grant Number:** 99-26

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Shah Etemad (203) 287-3700

**Organization:** Precision Combustion, Inc.

**Grant Amount:** \$75,000

**Status:** Completed

### Project Description:

Air emissions from combustion turbines used in mechanical and power generating applications are a major issue when seeking approval for installation. Oxides of nitrogen, NOX, are major constituents of those emissions. Gas turbine manufacturers have developed dry, low NOX (DLN) technology to reduce NOX emissions from over 200 parts per million to a range of 9 to 25 parts per million (ppm). These levels of emissions are achieved without the use of water or steam injection, or the use of selective catalytic reduction (SCR) devices in the exhaust. When SCR technology is combined with DLN technology the NOX emissions are reduced to the range of 2.5 to 5 ppm. This is the most common technology suite for large (>50MW) combustion turbines. Unfortunately SCR technology is very expensive making its use on the smaller combustion turbines uncommon. Smaller combustion turbines serve an important purpose in California's overall energy strategy when they are used in combined heat and power applications. In these installations over 70% of the energy of the fuel is put to productive use.

Researchers have determined the major reasons that DLN technology is limited to 9 ppm NOX. The primary reason is the use of a pilot burner to stabilize combustion over all operating conditions (i.e. startup, part load, full- load, and transients.) Without the pilot burner the engine could cease operation during various engine exercises. The pilot burner also reduces combustor "rumble", a vibration that can destroy an engine in a relatively short period of time. Although DLN pilots commonly burn only 2-5% of the fuel at full load, they are still the source of about 50% of the NOX emissions in a DLN burner. If the pilot burner emissions could be eliminated or reduced, a DLN burner could achieve NOX levels of less than 5 ppm.

This project tested the feasibility of using a catalytic stabilizer to replace the pilot burner in a regular DLN burner. The concept is to install the catalytic stabilizer in the fuel injectors (there may be 8 to 18 injectors in one DLN burner assembly). While catalytic combustion techniques have been under test for decades, those concepts replaced the entire DLN system with a catalytic system. The novelty of this concept is the use of catalytic technology only for the pilot burner, a small part of the overall combustion assembly. Full catalytic systems are large, often requiring extensive redesign of the engine casings. The catalytic stabilizer used in this project was built into an existing fuel injector without having to redesign major engine components. If this technology proves to be acceptable to the turbine manufacturers it could be readily retrofitted into combustion turbines already in the field. The use of the catalytic stabilizer could reduce DLN emissions to less than 5ppm NOX.

The catalytic reactor used in this study can begin and sustain operation at the relatively low outlet temperatures typical of today's combustion turbine compressors. That is the temperature of the air that after being compressed enters the combustion assembly. Operation of catalytic devices at such low temperatures (as low as 681°F) is unusual and a key feature that makes this concept work.



**Proposed Outcomes:**

The goal of this project was to determine the feasibility of building a catalytic stabilizer in place of the pilot burner in a standard engine fuel injector. The following project objectives were established:

1. Design the catalytic stabilizer to fit into an existing fuel injector for a Taurus 70 engine (Solar Turbines Inc.).
2. Determine if the catalytic stabilizer can begin and sustain fuel injector operations at the relatively low temperatures of the engine compressor outlet air. (Is a pre-burner required for the catalytic system?)
3. Achieve NOX emissions of less than 5 ppm for the Taurus fuel injector with the catalytic stabilizer replacing the standard pilot burner.
4. Determine if the catalytic stabilizer will allow leaner operation of the fuel injector.
5. Evaluate the operation of the catalytic stabilizer at a number of standard engine operating conditions.

**Actual Outcomes:**

1. The catalytic stabilizer fits into the existing Taurus 70 engine without major modification to the injector.
2. No pre-burner is required for the operation of the catalytic stabilizer. The catalytic stabilizer lit off at temperature around 355°C (671°F) during high pressure testing of the catalytic stabilizer – which is lower than the 435°C combustor inlet temperature.
3. The integrated catalytic stabilizer and the Taurus 70-injector assembly delivered NOX and CO emissions below 5 ppm.
4. The catalytic stabilizer allowed leaner operation of the injector.
5. The catalytic stabilizer demonstrated variable-load operability. In addition, low emissions were obtained at both 100% and 50% load conditions.

**Conclusions:**

The catalytic stabilizer was built into two Taurus 70 production fuel injectors. The modified injectors were operated at both ambient conditions and simulated engine pressures. Data supported the key objectives of the program. The catalytic stabilizer could be designed to fit into the space envelope allowed by the Taurus 70 fuel injector. It did begin and sustain operation without the use of a pre-burner. And low emissions were achieved.

1. There are potential cost advantages to this technology since major modifications to the injector were not necessary.
2. The modified fuel injector could begin and sustain operation without a pre-burner. The tests showed that no pre-burner is required for the operation of the catalytic stabilizer from half load to base load conditions for the Taurus 70 fuel injector. It also operated free from auto-ignition and flashback over a wide range of stabilizer fuel-air ratios and airflows. Auto-ignition and flashback can be major operational problems with fuel injectors resulting in severe engine damage.
3. The project successfully demonstrated NOX and CO emissions of less than 5 ppm at Taurus 70 baseload (high pressure) conditions for a single injector.
4. The project demonstrated that leaner operation in the upstream end of the combustor can be achieved by the catalytic stabilizer. Additionally, the results show that the catalytic stabilized fuel injector can achieve low emissions at lower inlet temperatures than those required for a "conventional" catalytic combustor.

The project demonstrated that sufficient catalytic activity can be achieved by both baseload and half load conditions to achieve stable combustion.

After this project was completed the California Air Resources Board (CARB) lowered the limits on regulated emissions, including NOX. This project achieved the targets that were based on regulations existing at the time of the proposal, as well as satisfied the new regulations with the effective date of 2003. However, the PA is concerned that the approach of this project will not provide an adequate operational safety margin in the emissions levels to satisfy the newly imposed regulations with the effective date of 2007. While this approach may find a broad world market with huge reductions in emissions world wide, it does not appear to be applicable in California in its current configuration.

### **Benefits to California:**

This project has contributed to the Public Interest Energy Research (PIER) program objectives for “Environmentally Preferred Advanced Generation” by advancing technology that will reduce emissions from combustion turbines typically deployed in mechanical and distributed power generation applications. Specific benefits are:

1. Improved air quality with cost savings. The catalytic stabilized fuel injector provides relatively low NOX levels at a low cost. Customers will ask the manufacturer of the gas turbine to guarantee air emissions. At this time the manufacturers have not indicated where they will guarantee an engine with catalytic stabilizers. If the guarantee level is below the level set by the California Air Resources Board for distributed generation, the catalytic stabilizer could be used throughout California to meet those regulations at reasonable costs.
2. Elimination of the use of ammonia to achieve low emissions. Ammonia is not used with the catalytic stabilizer. If gas turbine operators must install an SCR to meet low emission requirements, a measurable amount of ammonia would “slip” into the atmosphere.
3. Enhanced distributed generation. Californians will select gas turbine distributed generation more readily if the manufacturer can guarantee emission levels meeting the 2007 regulations. This will enhance the deployment of distributed generation and cogeneration within the state.
4. Improved air quality from retrofit. Manufacturers can apply the catalytic stabilizer technology to selected existing engines during an engine overhaul and upgrade without major modifications to the engine. These retrofits will further enhance the air quality of California.

### **Recommendations:**

This grant proved the feasibility of replacing a pilot burner in a DLN combustor with a catalytic stabilizer. All tests were done with single injectors in test rigs. In subsequent research the development team should reconfigure the technology to satisfy the 2007 CARB emission regulations, install it into an actual engine and develop the control algorithms for engine operation. Engineers should measure emissions levels and compare them with the 2007 CARB regulations for distributed generation. Engineers should also determine reliability and lifetime of the catalytic stabilized device. The provider of the catalytic stabilized device and turbine manufacturer must determine the costs to manufacture and install these devices and compare those costs to the costs of competing technologies.

The PA determined that the data generated during the initial grant was sufficiently complete and successful to recommend taking this technology to the next step of development. To meet the 2007 CARB regulations the catalytic stabilizer would have to be reconfigured. Though significant, reconfiguration should not be a show stopper. Continued cooperation with a major gas turbine manufacturer will accelerate the transfer of the technology into the marketplace. This technology will be of the greatest benefit to engines of less than 50 MW.

**Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

## Counter Rotating Wind Turbine System

**EISG Grant Number:** 00-09

**PIER Area:** Renewables

**Principal Investigator:** Kari Appa (949) 458-7314

**Organization:** Appa Technology Initiatives

**Grant Amount:** \$74,915

**Status:** Completed

### Project Description:

Most wind turbines in the world are single rotor systems, which provide simplicity, reliability and durability. Over the years, improvements have enhanced energy conversion efficiency of these single rotor systems. For example, blades have better aerodynamic characteristics, gears with reduced noise have better torque transmission efficiency, and alternators have better electrical efficiency. However, despite these improvements, single rotor systems are able to convert only a small fraction of the total wind stream energy into electrical energy.

Albert Betz predicted the maximum energy conversion efficiency of 59% when the axial wind speed is reduced by 2/3rd across a single rotor disc. However, practical wind turbines convert less than 40% of the wind energy into electrical energy. Hence, nearly 60% of the potential wind energy escapes without being harnessed. According to C. G. Curtis, the primary reason may be that a single rotor cannot be designed to achieve large changes in velocity or enthalpy. He therefore introduced the concept of velocity compounding using multiple rotors in tandem. This principle appears to be applicable to wind turbines as well.

This project investigated the power production and performance characteristics of a contra rotating wind turbine system.

### Proposed Outcomes:

The goal of this project was to determine the feasibility of improving wind energy conversion efficiency by utilizing a contra rotating wind turbine system. The researcher established the following project objectives:

1. Investigate performance of a contra-rotating dual rotor system as a means of enhancing wind energy conversion efficiency, targeting reduction of energy costs (\$/kWh) by 30%.
2. Develop designs for the contra-rotating dual rotor system for a low cost wind turbine (\$/kW). The designs should allow early and economical transition to the utility scale wind turbines.

### Actual Outcomes:

1. The project fabricated a prototype contra-rotating wind turbine system. The project team then installed the assembled unit on a 50- ft tower at the Oak Creek Energy Systems facility in Mojave, California. Tests conducted over a period of four months showed:
  - a. At lower rotor speeds, energy extraction increased by up to 40% over an equivalent single rotor wind turbine.
  - b. No detectable buffeting of the turbine blades occurred.
  - c. Bending stress on the supporting tower was reduced by the contra rotating system over the single rotor system.
2. The study identified design solutions to the problem of transmitting the net torque generated by a contra-rotating turbine system to an existing electrical power-generating unit. Because these solutions make use of existing hardware, they depend on the

configuration of the existing equipment on the targeted wind farm. Two separate solutions are presented.

**Conclusions:**

1. The field tests demonstrated that power conversion efficiency could be increased up to 40% by using a wind turbine with a contra-rotating rotor system versus a wind turbine with only one rotor. This increase will result in increased energy generation from a given tower installation, but the researcher did not relate back to the reduced energy cost target.
2. Power conversion efficiency was high at low rotor speeds, suggesting applicability of contra rotating turbines to large utility scale wind turbines that rotate at 16-20 rpm.
3. Buffeting can be a fatal problem leading to premature failure of a wind turbine. It is encouraging that buffeting did not occur on the contra rotating rotor system.
4. The contra-rotating system reduces bending stress on the tower. This reduced bending stress results when the torques produced by two rotors counterbalance each other.
5. There is a good prospect for a utility scale contra rotating turbine system to produce from 30% to 50% more energy from high and low speed wind farms in California. This prospect needs confirmation through further testing.
6. If the prospect of extracting additional energy as suggested in item 5 above is confirmed, this technology should find a market in the retrofit of existing wind farms. The project identified two fundamentally different approaches:
  - a. If the existing generator is provided with a dual winding (twin- generator) system, the same generator can be used for higher power rating. In this case, the shaft rotation power from the contra-rotating turbine is reversed in direction by a torque hub and combined with the existing turbine's power, both rotors driving the same generator.
  - b. If the existing generator is not provided with a twin-generator system, a second generator and the contra-rotating turbine can be added in a back-to-back fashion to the rear of the existing generator. This may require a new mounting platform or simply brackets to attach to the existing platform.

**Benefits to California:**

Successful commercialization of contra-rotating wind turbine systems could reduce the cost of electricity to California ratepayers, promote increased power production, and stimulate business and employment opportunities in wind turbine industries within California. These benefits would occur by producing more wind-generated power per acre of land and by using common facilities such as support towers and possibly generators. At this time, wind-generated electricity is the most economical renewable energy. In California, wind energy production is highest in the afternoon to early evening time period. This is also the time that demand for electricity peaks in California. Currently these demand peaks are met with relatively costly simple-cycle combustion turbines. Increasing wind power production would offset the need to run these "back- up" turbines. Air quality would also improve since simple cycle combustion turbines have relatively high emissions of NOX and CO.

**Recommendations:**

The present study demonstrated the feasibility of a contra-rotating wind turbine system by using readily available components. The next step is to design, build and test a utility scale, grid connected wind turbine system. A major task in the next steps is to assess cost effectiveness of the counter-rotating design.

The suggested next steps are as follows:

1. Select a grid-connected environment in the 50 to 100 kW power rating range.
2. Design and build the units to a cost target.
3. Team with a wind power production company to install one or more units.
4. Conduct power production performance studies with grid-connected power loading for a period of one year or more.
5. Assess the cost-effectiveness of dual rotor system versus the single rotor system using available data.
6. After successful completion of this study, plan to transition the technology by licensing to manufacturers or utility providers.

**Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

## Dev/Char of Improved Dye-Sensitized Nanocrystalline Solar Cells

**EISG Grant Number:** 99-10

**PIER Area:** Renewables

**Principal Investigator:** Jin Zhang (831) 459-3776

**Organization:** University of California, Santa Cruz

**Grant Amount:** \$75,000

**Status:** Completed

### Project Description:

A research group at the Swiss Federal Institute of Technology in Lausanne, Switzerland has developed a potentially low cost solar cell based on “sensitized” organic dyes and titanium dioxide, (TiO<sub>2</sub>, a material used in white paint). The Swiss technology has an experimentally determined, overall sunlight to electrical energy conversion efficiency of 7 -10 % under direct and diffuse sunlight. While this conversion efficiency is lower than the approximate 15 % of commercially available solar cell technology, the solar cell based on organic dyes and titanium dioxide offers advantages including environmentally friendly components, low temperature processing, and potentially lower costs to consumers. Calculations indicate that solar cells of at least 10 % efficiency could be realized at less than \$3 per Watt cost using the proposed technology. This may be competitive with conventional electricity generation in selected applications, and the approach could open up new markets in flexible solar cells used for consumer applications such as computers and cell phones, as well as in grid-connected distributed power generation. These markets are already over 100 Megawatts per year at a cost of approximately \$6 per watt. Patents for the new technology have been issued. To reach new markets the researchers may need to file additional claims for intellectual property protection.

Liquid electrolytes are volatile. Solar cells produced with liquid electrolytes suffer from reduced reliability and lifetime. The purpose of this project was to prove the feasibility of a method to reduce these technical shortcomings. While the existing state of the art of the new technology holds the promise to reduce costs for solar generated electricity, the reduced reliability due to the volatile liquids limits potential application of this technology. This project involved replacing the liquid electrolyte with suitable solids.

The researcher chose conductive polymers as the replacement for the liquid, specifically, polythiophenes.

### Proposed Outcomes:

The goal of this project was to determine the feasibility of replacing the volatile liquid in the dye sensitized nano-crystalline solar cell with conductive polymers. The following project objectives were established:

1. Determine if charge transfer can occur via the polythiophenes, and whether this material itself absorbs light.
2. If polythiophene does absorb light, determine if that absorption interferes and competes with light absorption by the dyes used in the state of the art device, and whether it can replace these dyes.
3. Measure the charge carrier dynamics of the dye, polymer, and TiO<sub>2</sub> suitable for this application. Construct an energy band diagram to better understand the functioning of solar cell with conductive polymers, and to optimize the solar cell output. Select an appropriate material based on these data.



4. Synthesize nano-crystalline TiO<sub>2</sub> films.
5. Fabricate, test and optimize solar cells using the materials exhibiting the best properties.

**Actual Outcomes:**

The following outcomes were achieved:

1. The researcher determined that polythiophenes could transfer charge and selected a hole-conducting polythiophene polymer. The researcher performed extensive tests on the absorption of light by the polythiophene and found that some polythiophenes can be both light absorbers and charge transporters.
2. One polymer, P3UBT, can act as a dye and a hole conductor possibly eliminating the need for a separate dye. This approach suffers from low mobility of charge carriers in the organic layer leading to low solar conversion efficiencies. For that reason, the grantee suggested using a separate dye and a separate transparent version of the polythiophene polymers along with porous TiO<sub>2</sub> in future work. A transparent polythiophene polymer will not interfere with light absorption by the dye.
3. This project measured charge carrier characteristics, constructed energy band diagrams and developed techniques to characterize materials suitable for the dye based solar cell. While specific polymer and dye combinations are recommended as a result of this work, the researcher recommends future work that will focus on materials with higher surface areas and therefore higher photocurrents.
4. The project synthesized TiO<sub>2</sub> films using sol gel depositing technique.
5. The researchers fabricated solar cells using sol gel deposited TiO<sub>2</sub> and the above polymer. They tested solar cell devices, and found that the junction properties are unique as well as efficient for the geometry selected. However the cells they created were single layer cells with an efficiency of only 0.032%. The grantee estimated that with 200 layers like the one reported, a solar cell with a solid electrolyte could be over 6% efficient. No further optimization work was reported.

**Conclusions:**

The researcher utilized TiO<sub>2</sub> materials, together with solid polymers to fabricate solid-state solar cells. These devices produced encouraging results given the fact that only a thin layer of polymer and a single layer of TiO<sub>2</sub> were utilized. Current voltage characteristics of devices fabricated using this technique are consistent with the energetics of the components, and are encouraging when compared to existing technology based on sensitization mentioned above. The researcher obtained expected results from a single layer of sensitizer (polymer), and a flat TiO<sub>2</sub> surface given the energy band diagram, and spectroscopic characterization. With the techniques and materials developed in this project, the researcher measured voltages over 0.8 V and current densities of 100 micro-amps per square centimeter of active area with one sun of illumination. These results, reported for the model system, are not related to performance needed in a commercial device. There is no indication in the final report of the magnitude of improvement needed for commercial success.

The goal of this project was to determine the feasibility of replacing the volatile liquid in the dye sensitized nano-crystalline solar cell with conductive polymers. Based on results, commercial feasibility may be possible if the emphasis is now placed on utilizing porous or multi-layer materials. The most critical issue for future work will be the extension to higher surface area materials that can result in higher photocurrents. Specific performance criteria should be established before subsequent work is begun.



**Benefits to California:**

At this point in the research, potential benefits to California can only be qualitatively estimated. The experimental results support the feasibility of replacing the liquid electrolyte with a conductive polymer. The long-term benefits to California ratepayers include lower cost solar cells. The cost of future cells produced with this technology is difficult to determine at this time. However, if the lower cost (\$3 per watt) is achieved, more ratepayers will install grid-connected solar power generators. These installations will help to diversify the California fuel portfolio. Increased utilization of solar energy to replace peaking power plants will greatly reduce the levels of CO<sub>2</sub> and NO<sub>x</sub> in the atmosphere.

There are other solar cell technologies that promise similar benefits. Sharp Corporation recently announced a new solar cell that employs organic pigments to change light into electricity. Sharp succeeded in switching the necessary electrolyte in the organic solar cell from the liquid state to a solid-state material. Sharp estimates that this new innovation will cut the cost of solar cells by one half. Sharp did not report an absolute cost or price.

**Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

## Direct Operation of Solid Oxide Fuel Cells on Natural Gas

**EISG Grant Number:** 99-30

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Scott Barnett (847) 491-2447

**Organization:** Northwestern University

**Grant Amount:** \$74,958

**Status:** Completed

### Project Description:

This research project targeted the generation of electricity using fuel cells with pipeline quality natural gas. A combination of factors – low noise, high efficiency, ultra- low emissions, and the ability to utilize readily-available natural gas – make fuel cells a generally desirable generation method.

Most fuel cell systems consume hydrogen derived from natural gas using some form of fuel processor. However, the fuel processor adds considerable complication and expense to fuel cell systems, exacerbating the problem of bringing costs down to competitive levels, especially for smaller plants. Until recently, it has not been thought possible to operate fuel cells directly on hydrocarbons. Recently low-temperature solid-oxide fuel cells (SOFC) have operated directly on methane. This demonstration signals an important new opportunity for making simple, cost effective fuel cells. Fuel cell operation on pipeline natural gas is considerably more difficult than operation on pure methane because pipeline gas contains higher hydrocarbons. This project developed a fundamentally new type of fuel cell anode with a specific anode composition. This anode was successfully tested on propane, a higher hydrocarbon constituent of natural gas.

### Proposed Outcomes:

The goal of this project was to determine the feasibility of anodic fuel conversion for a SOFC operating directly on natural gas. The key innovation was to develop the anode composition that satisfied the requirements for fuel cell operation. Subsequently the researcher verified that the higher hydrocarbons present in natural gas could be electrochemically oxidized without carbon deposition at the fuel cell anode. The following project objectives were established:

1. Develop multiple SOFC anodes based on Ceria with reduced Ni content and Ru-Ceria. During the project a third composition using a conductive ceramic was added.
2. Eliminate carbon coking on the anode when the SOFC is operating on propane. Characterize each anode performance by scanning electron microscopy for detection of carbon on the anodes, impedance spectroscopy, and fuel-cell current-voltage measurements.
3. Verify anode performance in a fuel cell stack. Select the most promising anode compositions for natural gas operation. Incorporate the selected anodes into fuel cells and test as a function of fuel composition and temperature.

### Actual Outcomes:

1. Ceria-based anodes with reduced Ni content, Ru-Ceria anodes, and anodes using a conductive ceramic with greatly reduced Ni were constructed. These anodes were evaluated and found to exhibit the required physical characteristics of porosity and conductivity. The conductive ceramic anode reduced the function of the metallic component to that of a pure catalyst. This allowed the researcher to make a major reduction in the amount of noble metal in the catalyst.

2. The anodes were characterized. Impedance spectra were found to be acceptable. Coking on the anodes was evaluated. Results showed that Ru and Ni provide similar electrochemical performance. Less coking was found on the anodes with reduced metal fraction. However, at very low metal content there is insufficient conductivity in the anode. From these data the research developed the innovation of replacing the metal with a conductive ceramic. This is a key outcome of this project. The innovative anode is composed of three materials, an electronically conducting ceramic, ionically conducting ceramic, and a metallic catalyst. It is highly resistant to coking.
3. Ceria-based anodes with reduced Ni content (Ni-GDC) and the ceramic Ni anodes were chosen for fuel cell testing. Initial performance using hydrogen fuel and air indicated only small differences between the two anode compositions. All subsequent testing focused on the ceramic Ni anodes. Performance using methane and air was found to be similar to known performance of prior methane fuel cells. When operating on propane fuel and air the ceramic Ni anode demonstrated improved performance when compared with the Ni-GDC anodes. Further, after several hours of operation at peak power the ceramic Ni anodes were free of coking while the Ni-GDC anodes showed heavy carbon deposition (gram quantities).

#### **Conclusions:**

1. This project has verified the feasibility of operating solid-oxide fuel cells (SOFC) directly on pipeline quality natural gas. In California the gas is composed of methane and higher hydrocarbons with controlled amounts of sulfur in the form of Mercaptans, an odiferous sulfur compound deliberately added as required by law for safety purposes. It is expected that these Mercaptans would be removed from the fuel fed to any operational fuel cell to avoid poisoning of the metallic catalyst. Removal techniques include use of activated carbon filters, zinc oxide or zinc acetate.
2. This project tested SOFC performance on higher-hydrocarbon components of natural gas, and showed that the fuel cells can be operated with propane.
3. After testing Ni-Ceria and Ru-Ceria anodes, the researcher determined that anodes with very low Ni content, using a ceramic conductor to provide anode conductivity, yield good performance. That is, they provide fast electrochemical oxidation, and hence high power densities, without carbon deposition.
4. This researcher utilized two ceramic constituents with an embedded metallic catalyst in his design approach. Because the relative amounts and the chemical nature of each of the three constituents can be altered to match a specific fuel or operating condition, a designer has great flexibility for improving fuel cell performance.
5. A major advantage of the new anodes is that they can be cyclically reduced and oxidized without degrading performance. This redox cycling is expected to occur regularly on periodic shutdown of small generators when the fuel flow is stopped. Thus, the new SOFC anodes may enable new applications of SOFCs that rely on the direct use of high energy density hydrocarbon fuels or feature frequent on-off cycling (e.g. portable power, auxiliary power units, and distributed generation.) While early stability tests of these anodes are promising, longer-term tests are needed.

#### **Benefits to California:**

The PA's assessment is that the benefits to be derived by the California electric ratepayer from the continuation and successful conclusion of this line of research accrue in the area of distributed generation. Distributed generation benefits directly by the availability of a quiet, low emission, cost effective power source using a readily available fuel. By operating on both natural gas and propane, these fuel cells can be configured as uninterruptible power sources for the communities they serve. By operating at an estimated thermal efficiency of from 40% to 60%, these fuel cells

reduce the amount of carbon dioxide produced per unit of electricity, thereby reducing the detrimental effect from this assumed greenhouse gas. By providing high grade heat, ~700 oC as a byproduct, the overall fuel efficiency of the distributed generation network can be improved substantially by situating the generator facilities as combined heat and power installations. Such a configuration is feasible given the quiet, non-polluting nature of fuel cells.

### **Recommendations:**

In order to advance this technology towards commercialization, R&D efforts must be carried out to improve and optimize the structure and composition of the new ceramic anodes for use with natural gas. This research should investigate and determine the following:

1. The effects of sulfur-containing compounds should be assessed, in order to determine whether a sulfur cleanup step will be required for the SOFC generators using these new anodes. If filtering of the gas is required, used filters should be evaluated for toxicity and their proper disposal should be considered.
2. The long-term behavior of SOFC fuel cells incorporating these anodes must be assessed.
3. The anode development work should include the criteria that the anodes achieve stable long-term performance.
4. The long-term test should include frequent cycling of operating conditions, including exposure to air, as expected in the real operation of small SOFC generators.
5. Finally, the anodes should be used as the support element of thin-electrolyte SOFCs. This will not only provide the best overall performance, but it matches the SOFC configuration being commercially developed.

This research effort should be undertaken in tandem with a commercializing partner. If these anodes can be incorporated into the existing SOFC configuration of commercial interest, it will maximize the commercial prospects for this new anode technology.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

## Energy Shaver-Thermal Energy Storage Device for Air Conditioner

**EISG Grant Number:** 99-16

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** James Lester (970) 963-2517

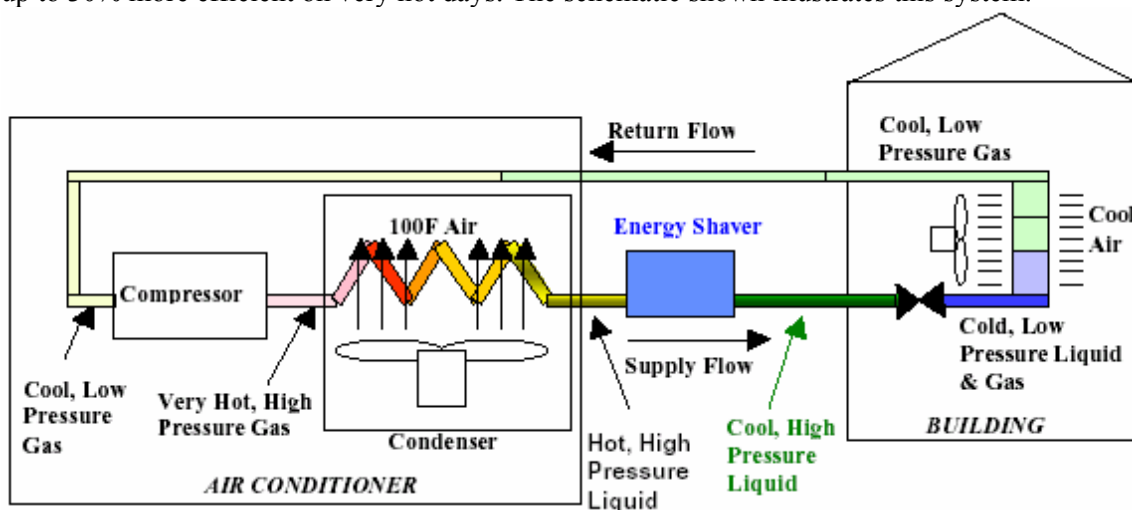
**Organization:** Redstone Engineering

**Grant Amount:** \$74,695

**Status:** Completed

### Project Description:

This project researched the feasibility of using a thermal energy storage device based on a salt hydrate to improve the performance of vapor-compression air conditioners of less than 5 tons capacity. A device using a salt hydrate to provide a relatively cool heat sink for the air conditioner working fluid during the hot part of the day was investigated. The stored heat is rejected from the salt hydrate to cooler night air to complete the cycle. With this device, an air conditioner can be up to 30% more efficient on very hot days. The schematic shown illustrates this system.



Thermal energy storage systems that use salt hydrates have been used for many years in solar heating systems. The innovation in this project is the use of salt hydrates for energy storage on the hot side of a vapor compression air conditioner.

### Proposed Outcomes:

The goal of this project was to prove the feasibility of using a salt hydrate energy storage device to improve the efficiency of existing vapor-compression air conditioners. The researcher established the following objectives:

1. Perform preliminary modeling of the air-conditioner/energy storage system.
2. Model the salt hydrate containers.
3. Select the energy storage system materials.
4. Model and bench test the heat exchanger and related components.
5. Perform final modeling of the energy storage system.

### Actual Outcomes:

1. The researcher wrote a FORTRAN computer program to model air-conditioning systems of 5 tons or less. This model used the FORTRAN-compatible Gaspak™ fluid properties program package to calculate refrigerant properties. A reciprocating compressor for the model was chosen. Future researchers must modify the model to incorporate the more

common scroll compressors. The project exercised the model for numerous sets of conditions.

2. This project found that an acceptable salt hydrate container is one that meets the heat transfer requirements with a pressure loss and airflow that can be obtained from a low cost fan. The surface area required for heat transfer for a 5-ton unit is 6306 in<sup>2</sup>. The project analyzed several container wall geometries for the heat exchange surfaces. The baseline configuration is a cylindrical annulus 48 inches high, 17.5 / 20.5 inches inside/outside diameter, and having pleated surfaces.
3. The researcher, through review of literature, identified several useful hydrates: calcium chloride hexahydrate, sodium sulfate decahydrate, disodium phosphate dodecahydrate, and mixtures of sulfate and phosphate hydrates. These hydrates are compounds of salts and water in which the water bonds to the salt molecules when the temperature drops below the freezing point of the hydrate. This gives the hydrate a large latent heat of fusion that is released when the water/salt solution freezes. The selected mixture was 5/35/60% phosphate/sulfate/ water with 3% borax additive.
4. The researcher substituted water for Freon<sup>™</sup> in the system bench test. Tube spacing, container wall spacing and the hydrate were the same as in the planned, full-size energy storage device. For the heat flux per degree of temperature difference to be the same for the full-size energy storage device and the bench-test energy storage device, a scaling factor was calculated. Using this scaling factor the researcher built a bench-test heat exchanger tube six feet long to maintain equivalent heat transfer.
5. The project iteratively updated the model of the energy storage device and incrementally improved it during the project bench test. The researcher incorporated the results of the tests as well as the empirically determined heat transfer coefficient in the model.

### Conclusions:

The project results indicate the technology is feasible and the salt hydrate energy storage device could provide measurable benefit when installed in an existing system. On a new or replacement system, the user would see immediate cost savings from reduced demand charges and energy consumption. The researcher suggests new replacement air conditioners equipped with the salt hydrate energy storage device could be smaller, therefore, they could cost the same as or less than the larger units they replace. This would offer an immediate payback.

1. The system modeling produced the following conclusions:
  - Project results indicate a demand reduction of 25% and an energy savings of 23% are possible when a 3-ton air conditioner augmented with the energy storage device replaces a 4- ton air conditioner. (The researcher made an unwritten assumption that comfort levels would be equivalent.) Energy savings are negligible for a simple retrofit into an existing air conditioning unit.
  - Retrofit applications require modifications to the air conditioner evaporator to realize maximum benefits.
  - The energy storage device is best suited to applications where dehumidification is usually required.
  - The melt/freeze cycle operates with normal ambient conditions.
2. Data from the salt hydrate modeling and testing led to the following conclusions:
  - A nucleating agent is required to stabilize the refreeze temperature.
  - Some salt settling occurs with the selected mixture, resulting in a loss of thermal capacity of about 5%. Mixing or some other measure is needed to maintain long-term thermal performance. Additional energy is required for the mixing operation.
3. The researcher identified and used effective combinations of known salts for the energy storage device.

4. Bench tests led to the following conclusions:
  - The scaled version of the Freon<sup>™</sup>-to-salt heat exchanger design did not perform as well as expected. The outlet temperature rose 22°F by the end of the test when the model predicted a rise of 18°F.
  - Although the performance is adequate, additional heat transfer area (longer tubes or extended surfaces) is necessary to meet the stated heat transfer requirements.
5. The project produced data that has been incorporated into a model of the system. Future researchers in this field can use these data and the updated model.

#### **Benefits to California:**

Electric power demand exceeds supply during hot summer days in many areas of the state. A large percentage of peak power demand is driven by air conditioning demand. Expanding new house construction in hot areas of the state is magnifying the problem. Almost all of these houses are equipped with air conditioning.

The salt hydrate energy storage device tested in this project would have a measurable impact on the California's energy consumption if it were widely implemented in new and replacement applications. Negligible benefits were found for simple retrofit. A significant portion of California has weather suitable for using this thermal storage device.

#### **Recommendations:**

Two major areas requiring further development are mixing of the salt hydrate to ensure repeatable, long-term performance and product packaging to integrate the salt hydrate energy storage device with new or existing air conditioning equipment. Salt based energy storage systems, while offering great advantages to energy storage, have problems of heat transfer, settling, corrosion, and often cost. The PA recommends research work on these problems. Once solutions are found, the researcher should team with a manufacturer of air conditioning equipment to test a prototype energy storage system for energy performance and user comfort.

#### **Progress Made Subsequent to the Initial Report:**

The Energy Shaver is now called the Therma-Stor Cooling Booster (TCB).

The TCB has been developed and refined over the last four years. Each iteration resolved technical challenges and improved the design. Two major technical challenges that have been resolved are effective heat exchange with and long-term performance of the salt hydrate. The TCB is now in the I&I Category 2, Stage 3 Development stage.

A residential field test in the summers of 2001 and 2002 in Boulder, Colorado proved that the TCB increases efficiency and cooling capacity. In the test, a two year old 10 SEER 4-ton air conditioner was replaced with a new 10 SEER 3-ton air conditioner incorporating the Therma-Stor Cooling Booster. The extra cooling provided by the TCB enabled the 3-ton unit to cool the 2450 square foot residence to a low of 73°F with an outdoor temperature of 95°F. This was two degrees warmer than the 4-ton unit could achieve. The cooling demand, however, was easily met when the thermostat was set at 75°F. Energy measurements showed electric current demand dropped from 19.5 amps to 14.5 amps at 230 VAC, thus reducing peak demand by 1.15 kW. The TCB boosted the cooling well into the evening, at which time extra cooling was no longer needed. The fan consumed approximately 1.5 kWh each night to reject heat from the TCB and prepare it for the next day. Figure 1-2 shows the 4-ton unit and the 3-ton unit with the TCB. Figure 1-3 shows test data of the 3-ton unit with and without the TCB. Note that when the TCB is on, the Freon temperature at the TCB outlet (blue line) is much lower than when the TCB is off. This colder Freon produces more cooling at the expansion valve and evaporator in the house.



Although this test successfully replaced a 4-ton unit with a 3-ton unit, the proposed program will take a more conservative approach. New units having ½ ton less rated cooling capacity than those typically required will be installed.

**Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.



## Energy-Efficient Air-Handling Controls

**EISG Grant Number:** 00-12

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Clifford Federspiel (510) 418-3392

**Organization:** Federspiel Controls

**Grant Amount:** \$75,000

**Status:** Completed

### Project Description:

A large fraction, in some cases as much as 24%, of the energy consumed in buildings is used to operate fans that move air for heating, ventilating, and air-conditioning (HVAC). Much of the fan energy is wasted because fans are not operated in the most efficient manner. Inefficient fan operation can increase cooling energy consumption as well as fan energy consumption when their operation causes more air to be cooled than is necessary. Furthermore, inefficient operation of HVAC fans increases grid peak demand when electricity demand is high.

If fans could be operated efficiently, moving only the air needed, when it is needed, then savings would accrue in two areas. First, the fans would operate for less time, reducing their energy consumption by 20 to 40% and second, less fan operation means reducing the mass of air that requires cooling. This excessive or wasted cooling energy is estimated to be 10% of the total.

The researcher in this project proposed to develop new, more energy efficient strategies for operating air-handling equipment. To quantify the potential savings of these strategies the researcher embedded them into an analytical model. The model predicts the transient response of pressures, velocities, and temperatures in the system and uses sequential modes of operation to approach the set point. Actual data from a large office building in Oakland, California, were used to calibrate the model. The researcher developed a new model based on two strategies. The first strategy, called “Efficient Air-handling StrategY” (EASY), is a system control that can be implemented with a finite state machine in which states are modes of operation such as “economizer enabled” or “economizer disabled.” The second strategy, called “Static Adjustment based on Volume flow” (SAV), employs resetting static pressure based on supply airflow rate. SAV can be implemented as part of EASY or as a standalone strategy. The researcher tested both strategies and found the majority of the benefits derived from SAV.

### Project Objectives

The goal of this project was to determine the feasibility of using an intelligent ventilation fan controller to reduce the energy consumption of the fan by more than 20%. The specific objectives of the project were as follows:

1. Develop, using optimization and computer simulation methods, a new energy-efficient algorithm to control air-handling equipment in buildings.
2. Reduce fan energy consumption by 20%-40%.
3. Reduce cooling energy consumption by 10%.
4. Demonstrate stable operation of the fan controls while minimum ventilation, appropriate building pressurization, and appropriate temperature control are maintained at all times.

### Project Outcomes:

1. The researcher used an existing model of air-handling systems for a starting point. The researcher calibrated the model using data from the Elihu Harris State Office Building in Oakland, California. The researcher determined optimal system behavior and then

- identified patterns of behavior that could be encoded as control rules. The rules were designed to achieve nearly optimal performance.
2. The researcher expected reductions in energy consumption from reduction of throttling losses at the control dampers (exhaust, return, and outdoor air dampers) of the air-handling unit. The researcher reported fan energy savings of 26.3% over the base case. However, the researcher chose a system with no static pressure reset as his base case. There are existing control schemes that use static pressure reset that are reputed to perform as well as or better than EASY with SAV. When compared with state-of-the-art systems the strategies developed in this project may or may not have a comparative advantage.
  3. The researcher expected gains in cooling energy to arise from better control over outdoor airflow rates. Existing systems using fixed minimum damper positions for regulating outdoor airflow can over-ventilate when it is hot, increasing cooling energy consumption. The project strategy directly controls outdoor airflow rate. Cooling energy savings were reported to be 17.4%. Again, the researcher compared his results to a base case with no static pressure reset. The comparative advantage to state-of-the-art systems may be considerably less.
  4. The researcher invented a simpler way to model the behavior of fans. The researcher could not get the optimizer code to converge to the best operating point. Instead, he used trial and error methods combined with knowledge of existing strategies incorporating his findings into the EASY code. With these modifications, the models were stable and met minimum HVAC conditions required for a building. The researcher reported a faster system response time for his control system.

### Conclusions:

The feasibility of the intelligent fan control strategy was proven.

1. The control strategies developed in this project cause a fan system to use less energy than the base case while ensuring that control requirements are met at all times.
2. The control strategies can reduce fan energy consumption by as much as 26.3% when compared to a system without static pressure reset.
3. The control strategies can reduce cooling energy consumption by as much as 17.4% when compared to a system without static pressure reset.
4. The control strategies appear to be easier to tune than existing strategies. They exhibit faster response time when tuned properly. System settling time was reduced to 30 minutes from two hours.
5. The researcher should clearly establish the technology baseline against which he is calculating his energy savings calculations. He should compare to the best available technology.

### Benefits to California:

The project demonstrated the proposed control strategies could reduce average power by 0.23 W/ft<sup>2</sup>/year in buildings with variable air volume (VAV) air-handling units. This is a large potential reduction in energy consumption. The researcher's calculation is based on the premise that static pressure reset is neither widely employed nor available. Based on data from DOE, the researcher estimated the proposed control strategies, if implemented in all applicable buildings, would reduce energy costs by \$928 million/year nationwide and \$171 million/year in California. Primary beneficiaries would be the owners and/or operators of large air-handling systems incorporating variable air valve technology. Other ratepayers would benefit from the decreased load on the grid during peak demand periods.

**Recommendations:**

The researcher is encouraged to survey manufacturers of controls for VAV systems to determine what is commercially available. Energy savings calculations should be based on the best available technology rather than the most commonly deployed. Alternately the researcher could find his concept provides large energy savings at costs significantly lower than the best technology available today. If that market study confirms a large energy savings potential, then a field test is recommended to quantify and validate the energy efficiency benefits in a large building. The tests should be conducted during the summer so cooling energy benefits and fan energy benefits can be quantified. A widely accepted test procedure should be followed to establish credible data. Methods for commissioning SAV to produce the largest energy benefits could also be investigated.

**Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Completed.

## **Increasing Efficiency of Geothermal Energy Generation with High Resolution Seismic Imaging**

**EISG Grant Number:** 00-10

**PIER Area:** Renewables

**Principal Investigator:** Dimitri Bevc (650) 969-3886

**Organization:** 3DGeo Development, Inc.

**Grant Amount:** \$75,000

**Status:** Completed

### **Project Description:**

This project targeted an important energy source in California, geothermal energy. The researched seismic imaging technology has the potential to reduce the cost and risk associated with exploration and development of geothermal resources. This technology may lead to increased utilization of California's extensive geothermal resources, which provide an environmentally sound alternative to fossil fuels.

High-resolution reflection seismic imaging has been very successful in oil and gas exploration. It is the number one pre-drilling risk reduction technology and is applied on a routine basis to oil and gas exploration and production projects. Seismic technology has substantially reduced exploration cost, exploration risk, and environmental impacts. Despite its promise, reflection seismic imaging has not been applied extensively or with great success to geothermal exploration.

This project has applied existing, tested, oil and gas exploration algorithms to geothermal field seismic imaging data. The results demonstrated the potential utility of high-resolution reflection seismic imaging applied to geothermal objectives. They represent an improvement over previous research results and demonstrate that application of state-of-the-art seismic imaging technology and methodology may be beneficial in geothermal applications.

### **Proposed Objectives:**

The goal of this project was to determine the feasibility of applying high-resolution reflection seismic imaging in the geothermal environment to map geothermal reservoir zones. The researcher established the following project objectives:

1. Modify imaging algorithms for application to the seismic imaging data acquired at the Coso geothermal field.
2. Preprocess reflection seismic data acquired at the Coso geothermal field.
3. Generate a high-resolution wave equation migrated image of the Coso geothermal field.
4. Determine the validity and accuracy of seismic imaging by comparison to drilling data, other geological/geophysical information, and prior processing results.

### **Actual Outcomes:**

1. The researcher made minor modifications to the algorithms to read and to fully utilize the Coso geothermal field seismic imaging data.
2. The researcher implemented a near-surface velocity model using first-arrivals from the seismic data and turning ray tomography inversion. This implementation removed near surface distortions.
3. The researcher generated high-resolution wave equation migrated images of the Coso geothermal field using each of the following methods: a) 3DGeo's ComAz wave-equation migration algorithm, b) pre-stack time migration, c) post stack time migration, and d) pre-stack Kirchhoff depth migration.

4. The researcher compared the images to prior existing images, published geological and geophysical information, and analyses. The project compared the velocity models to results previously obtained by other workers. The project validated the new high-resolution images against the known geology.

**Conclusions:**

1. This project has taken the first step in validating the application of 3DGeo's proprietary seismic imaging technology to a California geothermal data set.
2. Geothermal areas generally produce challenging seismic data that push the limits of processing and imaging technology. This project has demonstrated the challenges can be overcome through the proper application of state-of-the-art seismic imaging technology.
3. Active source reflection seismology appears to offer benefits to geothermal exploration and development. High quality seismic data processing is important to obtain accurate and usable imaging results. The quality processing is not limited to the high-end imaging algorithms such as Kirchhoff migration, but also is valuable in the preprocessing applied to data. Statics and pre-stack noise attenuation appear to be important to obtain a good imaging result.
4. The images generated in this project appear to support the proposed methodology for processing geothermal field seismic data. The major goal of this study was to demonstrate that seismic imaging of structures could be obtained in heterogeneous geothermal environments. Therefore, the researcher assessed the success of the experiment by reference to the seismic imaging results themselves and the fact that knowledgeable geophysicists could identify known geologic structure from the images. While interpreting the images remains an art, there does appear to be more details in the new images that have a positive correlation to the known geology.

**Benefits to California:**

Because this technology can lower the cost of finding and producing geothermal energy the electric ratepayer will receive economic and environmental benefits. The California Legislature recently passed SB1078 that mandates utilities to provide 20% of their electricity from renewable resources by 2017. Technologies such as the one demonstrated in this grant will both lower the cost of developing the required resources, and also may lead to discovery of more geothermal resources within the State. The increased utilization of California's renewable geothermal resources will benefit the State as a whole by reducing the need to import and consume increasingly costly conventional fuels. Reduced consumption of fossil fuel will also improve California's air quality.

**Recommendations:**

The PA recommends further processing of the remaining Coso data. Researchers should acquire another 2-D or preferably 3-D survey in Coso or elsewhere for further imaging and demonstration of the technology in a larger more in-depth effort. Further development of this technology through a large-scale demonstration will clarify its capability by giving an example of its full potential.

**Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Completed.

## Modeling Greenhouse Temperature for Energy Efficient Production

**EISG Grant Number:** 99-08

**PIER Area:** Industrial/ Ag/ Water

**Principal Investigator:** Heinrich Lieth (530) 752-7189

**Organization:** University of California, Davis

**Grant Amount:** \$75,000

**Status:** Completed

### Project Description:

California is the leading state in the US floriculture industry, with wholesale value over 700 million dollars per year. With more than 115 million ft<sup>2</sup> area under greenhouse cover, California has the largest area of protected crop production facilities in the nation [National Agricultural Statistics Service, USDA. 1998].

Greenhouse agriculture requires considerable energy for cooling in the summer and heating in the winter. While computers have been incorporated into most greenhouses, no significant environmental control software exists. Each crop that might be grown in a greenhouse has different temperature requirements. Proper use of an accurate crop model embedded within greenhouse environmental control software will enable achievement of the optimum energy efficiency for the greenhouse crop combination.

### Proposed Outcomes:

The goal of this project was to determine the feasibility of embedding a sufficiently detailed and accurate model within the greenhouse environment control software to enable optimum energy efficiency for the greenhouse crop combination. The researchers established the following project objectives:

1. Create and integrate greenhouse climate models with crop models.
2. Validate the integrated model.
3. Develop general-purpose energy management software tools that growers could use to assist in greenhouse energy management.

### Actual Outcomes:

1. A full-sized, large-scale simulation model was developed that simulates the greenhouse climate in relation to the control objectives, the outside climate, the crop growing in the greenhouse, and the various management practices. This model was then implemented on a computer simulation system. The size and complexity of the model was such that the high-end computer workstation it was hosted on would only simulate short time frames. The researcher could not fully exercise the computer model due the excessive memory demands of the program, even when running on a high capacity workstation. Evaluation of this implementation was not completed.
2. Partial validation of the model was performed. The simulation model behavior was satisfactory in most areas except for its inability to accurately predict the air temperature and humidity inside the greenhouse in the winter.
3. A software tool was developed that allows growers to calculate temperature set points in relation to rose-crop development for cut-flower roses. Presentations and training sessions at national grower meetings (March 30, 2001 Denver, Colorado) have been conducted to assist growers in using the software. The software tool was made available to the public through publication on the web to allow easy access by the greenhouse

operators. The Principal Investigator has indicated that this software tool has been downloaded for use by rose growers in California.

### **Conclusions:**

1. Considerable insight was gained into the many variables that impact greenhouse thermal properties. The complexity of the modeling and simulation was greater than originally anticipated. The size and complexity of the model and its inability to run effectively, even on a high end computer workstation, makes the model impractical for real time greenhouse control in its current configuration. The accuracy of the integrated model was impacted by errors contained in existing models/data.
2. Further work is needed to validate and optimize the model for accuracy before it can be used for comprehensive energy simulations. Feasibility of integrated greenhouse climate models with crop models has yet to be established.
3. Due to the complexity of the various crop models it may not be possible to create general purpose energy management software tools that could be applied to a variety of crops. Instead, it appears that the software tools will need to be tailored to specific crops, which will require considerable research and development.

### **Benefits to California:**

Greenhouse growers will benefit directly from the tool that was developed as part of objective 3 of this project. The tool is particularly targeted to cut-flower rose growers, to assist them in selecting temperature set-points that will allow them to schedule crop maturation to coincide with holiday sales. This tool allows growers to maximize profitability by optimizing productivity through precise energy management. Energy use by cut flower growers may be reduced by use of this energy control tool.

### **Recommendations:**

The simulation system, as an analytical tool, will require considerably more work before it will result in widespread practical applications for greenhouse energy management. Additional work is needed that would allow the model to run effectively on a standard computer. The model needs additional development to make it more accurate in the areas of noted deficiency. Specific crop models need to be developed that can be integrated into the greenhouse climate model.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.



## Non-Vacuum Thin-Film Photovoltaics Processes

**EISG Grant Number:** 99-31

**PIER Area:** Renewables

**Principal Investigator:** Chris Eberspacher (805) 987-7258

**Organization:** Unisun

**Grant Amount:** \$75,000

**Status:** Completed

### Project Description:

Photovoltaics (PV) is a small but rapidly growing sector of California's electrical power generation capacity. For PV to significantly impact the State's economy and quality of life, the cost of PV-generated power must decrease. One of the most promising strategies for lowering PV costs is the use of technologies in which thin films of materials are deposited on inexpensive substrates like window glass. One of the most promising thin-film materials is copper indium gallium selenide ( $\text{CuIn}_{1-x}\text{Ga}_x\text{Se}_2$  or CIGS).

Vacuum deposition processes have difficulty depositing CIGS films on large areas with the precision and control necessary to achieve low manufacturing costs. Non-vacuum deposition techniques provide a simple, low-cost alternative. Preparing fine powders of precursor materials, depositing thin layers of the particulate precursor materials, and sintering the layers into high-quality dense films can form high quality thin films.

Simple, non-vacuum techniques such as spraying and printing can deposit layers of particles on large-area substrates. Exploratory materials research using simple pneumatic spraying yielded cells with 11.7% efficiencies and monolithic multi-cell modules with 5% efficiencies. However, the sprayed layers were not very planar (i.e. flat) and were not very well packed (i.e. dense), and deposition rates and materials use efficiency were low. The aim of this EISG project was to deposit uniform, planar, well-packed layers with high materials use efficiency (MUE).

### Proposed Outcomes:

The goal of this project was to determine the feasibility of depositing planar, well-packed particulate layers at high rates with high materials use efficiency (MUE) using non-vacuum techniques. The researcher established the following project objectives:

1. Identify high-MUE, non-vacuum deposition techniques and obtain suitable equipment for experimental evaluation.
2. Develop high-MUE spraying techniques using CIGS precursor materials.
3. Fabricate efficient thin-film PV devices using high-MUE techniques.

### Actual Outcomes:

1. The researcher identified high-MUE, non-vacuum deposition techniques and procured suitable equipment for experimental evaluation.
  - Pneumatic spraying resulted in good atomization and excellent spray directionality, but materials use efficiency was low.
  - Without gas assistance, ultrasonic spraying resulted in good atomization, but the lack of carrier gas resulted in poor spray directionality.
  - Gas-assisted ultrasonic spraying yielded good atomization and good spray directionality.
  - Electrostatic spraying at 30 kV yielded relative materials use efficiency gains of 50-65%, but the deposition pattern was erratic and irreproducible.



- Casting and spray casting yielded high materials use efficiencies and well-packed, planar layers.
2. The researcher developed high-MUE deposition techniques for depositing layers of CIGS precursor particulate materials.
    - The morphology of particle layers deposited by pneumatic spraying varied with spraying conditions.
    - Layers sprayed in a manner that facilitated rapid local solvent evaporation exhibited microscopically planar surfaces.
    - Layers sprayed using slow solvent evaporation conditions exhibited non-planar surfaces characterized by a network of ridges and valleys.
    - Droplet drying mechanisms resulted in observed morphological variations.
    - Individual droplets of well-dispersed, well-suspended slurry dried to form rings of particles.
    - Networks of ridges and valleys evolved as particles were differentially collected into ridges by the interplay of ring overlap, particle bounce-back, high-angle over spray, and particle/gas lateral flow.
    - Spray conditions that facilitate rapid solvent drying mitigated local drying effects that cause non-planar layer morphologies but such conditions reduced materials use efficiency.
    - Ultrasonic spraying minimized particle loss mechanisms and yielded higher materials use efficiencies, however, ultrasonic spray deposition resulted in non-planar layers characterized by ridges, valleys, and small agglomerates.
    - Spraying under conditions that mitigate in-flight droplet drying sharply reduced the density of small agglomerates but slow-evaporation conditions aggravated the tendency to form a ridges and valleys topology.
    - Casting techniques, which use a continuous “wet film” of slurry rather than isolated droplets, circumvented the non-planar morphologies that result from cycles of wetting and drying.
    - The substrate-wide drying front inherent to solvent evaporation from continuous wet films minimized the formation of ridges and valleys.
  3. The researcher fabricated thin-film PV devices using particulate precursor materials deposited using high-MUE techniques, achieving cell efficiencies of 9.4%.

**Conclusions:**

1. The results demonstrate high-MUE deposition processes can yield PV devices with the efficiencies needed to fabricate commercially viable products.
2. Cost-effective formation of high-quality PV films using particle-based, non-vacuum processes requires the deposition of reasonably planar, well-packed layers of particulate precursor materials with high materials use efficiencies.
3. Non-vacuum spraying techniques provide the necessary combination of planar, well packed layers and efficient materials use provided one mitigates nozzle-related agglomeration, avoids repeated wetting/drying that can cause non-planar morphologies, and facilitates particle rearrangement that can increase packing densities. The demonstration of efficient spray deposition of planar, well-packed layers lays the foundation for the fabrication of efficient, large-area, thin-film PV modules using non-vacuum processes.

4. Since the techniques developed in this project can yield higher particle packing densities in particulate precursor layers, improvements to final film quality can accrue from adjustments to the reactive sintering processes used to convert porous precursor layers into dense final films.

**Benefits to California:**

If this line of research reaches a successful conclusion, California will benefit in several ways. Rooftops equipped with solar power systems provide customers the option of generating their own clean, quiet, reliable electricity. Solar power, with its ability to provide electricity at home or at a business site, can help offset the need to purchase electricity and increase consumer autonomy. PV technologies based on thin films can potentially deliver the end- user price reductions necessary to expand the use of PV significantly and aid California ratepayers in realizing a pollution-free, renewable energy option.

**Recommendations:**

The techniques developed in this project yield efficient small-area solar cells. Further research is needed to test these techniques in the fabrication of larger-area, monolithically integrated, multi-cell modules suitable for commercial production. The next steps are:

- Investigate synergies that might arise from combining improved particle layer deposition techniques with improvements to the layer-to-film sintering processes.
- Apply the high-MUE particulate layer deposition techniques to the fabrication of large area, multi-cell modules.

**Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

## Novel Composite Membranes for Fuel Cells

**EISG Grant Number:** 99-19

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Sossina Haile (626) 395-2958

**Organization:** California Institute of Technology

**Grant Amount:** \$74,942

**Status:** Completed

### Project Description:

Fuel cells utilizing a polymer electrolyte membrane (PEM) have the desirable characteristics that they operate at near room temperature with high power density. A less desirable characteristic of the proton-conducting polymer is that it utilizes water, in the form of the hydronium ions,  $H_3O^+$ , as the proton conductor. This leads to a requirement for water re-circulation and temperature control in the system. In addition, the need to maintain hydration limits the maximum allowable temperature and results in low efficiency in hydrogen-air fuel cells. PEM fuel cell operating at higher temperatures can demonstrate improved efficiency and reduced carbon monoxide poisoning of the catalyst.

If a substitute for the hydrous component in the fuel cell membrane were found, manufacturers could eliminate the need for water re-circulation, relieve thermal management issues and achieve the benefits of higher temperature operation's increase of catalyst efficiency in generating protons at the fuel cell anodes. This benefit is directly applicable to all PEM fuel cells including hydrogen/air fuel cells, and cells fueled by reformed hydrocarbons. These fuel cells are typical of those applied to power generation.

Many solid acids exhibit excellent proton transport properties, but less than ideal mechanical properties and chemical stability. For these reasons, the researcher selected and investigated composite materials utilizing an inert polymer matrix to support the embedded solid acid.

### Proposed Outcomes:

The goal of this project was to determine the feasibility of using proton-conducting membranes that do not rely on hydrated polymer for proton transport in a PEM fuel cell. The proposed membranes are composites of inert polymers and "solid acids." The following project objectives were established:

1. Prepare, characterize and evaluate a broad range of polymer/solid acid composite membranes for subsequent development of membrane electrode assemblies.
2. Fabricate and Characterize electrodes and membrane-electrode assemblies. Understand and optimize electrode microstructure.
3. Demonstrate a single cell fuel cell utilizing a solid acid based membrane operating at temperatures between 100 and 180°C.

### Actual Outcomes:

1. A large number of composite membrane systems (more than 12) were prepared, characterized and evaluated. The majority of these systems exhibited low conductivities and poor homogeneity, although some, notably composites formed using a ceramic matrix, had conductivities within an order of magnitude of the solid acid alone and excellent reproducibility. Because of the higher conductivity of the solid acid alone, such membranes (in which the inert matrix material was eliminated) were used for further fuel cell development.

2. Membrane electrode assemblies were fabricated using various techniques. The most successful technique discovered was the simultaneous cold-pressing of the electrode/electrolyte/catalyst layers and the electrolyte membrane material. A volatile organic (naphthalene) was added to assure porosity. These assemblies were very thick because of the need to assure impermeability of the solid acid layer.
3. Fuel cells were demonstrated using several variations of electrode/electrolyte/catalyst layers. They can be generally characterized as exhibiting an open circuit voltage ranging from 1 to 1.12 volts, and producing power ranging up to 12 mW/cm<sup>2</sup>.
4. An unanticipated outcome of this research was the discovery that in a reducing environment (flowing hydrogen) the sulfur content in the solid acid reduced to H<sub>2</sub>S. The rate of conversion was higher in the presence of a metal catalyst. This chemical reaction limits the long-term stability of these fuel cells. Solid acids not containing sulfur were shown to be stable, but as of yet no solid acid combining high stability and high conductivity have been identified.

#### **Conclusions:**

Knowledge was gained and conclusions were drawn from each step in the progress of this project as detailed in Appendix A. The researcher summarized the project in these words

"The problem of sulfur (or selenium) reduction has proved vexing indeed. The development of optimized membrane electrode assembly structures awaits the discovery of alternative solid acids with greater chemical stability (materials that exclude sulfur and selenium)." This project determined that the use of proton conducting membranes that do not rely on hydrated polymers for proton transport in PEM fuel cells is not feasible using *current* solid acid materials.

#### **Benefits to California:**

In this project it was demonstrated that the path to a successful energy product that will benefit California electric ratepayers requires as its first step the development of alternative solid acid materials. It cannot be predicted at the outset whether such materials will be discovered.

#### **Recommendations:**

The basic thesis for this project was sound and the research was carried out in a professional and competent manner. Unfortunately the chemistry involved did not result in a usable anhydrous membrane material. If one is to realize the potential advantages of anhydrous, thermally stable proton conductors, "alternate solid acids with greater chemical stability" must first be discovered.

#### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

# EISG Projects Completed in 2002

## Anaerobic Pump

**EISG Grant Number:** 99-38

**PIER Area:** Renewables

**Principal Investigator:** Keith Schimel (315) 425-7741

**Organization:** Technology Matrix Corporation

**Grant Amount:** \$71,000

**Status:** Completed

### Project Description:

Anaerobic digestion, as it is currently practiced, is limited in application because incomplete biochemical reactions severely limit the extent of the biological production of methane. This limitation is mainly due to the resistance to decomposition of many complex solid organic substances that constitute wet biomass.

In 1980, Dr. Keith A. Schimel invented a new continuous flow, continuous culture anaerobic process which was shown to nearly complete the digestion of wet biomass solids with an ordinary mixed culture of anaerobes. The design concept of this process is based on using the product biogas to plasticize the residual solids. In these early tests, development was focused on solids reduction and doubling the normal digestion speed of raw waste activated sludge. The data showed as much as 90% volatile solids (Organic materials) reduction and 80% chemical oxygen demand reduction could be achieved if the process is operating at optimum.

In the current project the focus was to validate the high solids reduction and improve the process's biogas (primarily methane) production. Methane produced by this process can be used to fuel electricity power plants in California. If deployed the technology could not only play an important role in the reduction of wet biomass solids, it could also provide a significant amount of fuel gas (methane) for power plants.

The project compared the methane production performance of this advanced hydrolysis and biogasification process with a conventional digestion process. Two prototype reactor systems were implemented. The advanced hydrolysis and biogasification process and a conventional, single-stage, "completely mixed by stirring" (CSTR) digester were operated side by side under identical conditions. Both systems were fed the same substrate, a 50:50 mixture of wastewater sludge at the same loading rates. This substrate is commonly used as a test substrate because it is widely available and is difficult to degrade. Both systems were held at the same low incubation temperature (20°C) so that accurate observations could be made.

### Proposed Outcomes:

The goal of this project was to determine the feasibility of using the advanced hydrolysis and biogasification process for significant production of power plant fuel (biogas) by the reduction of wet biomass solids. The performance of the prototype reactor system implementing the advanced hydrolysis and biogasification process was compared with the performance of the CSTR reactor, the conventional technology used to reduce wet biomass solids. The following project objectives were established:

1. Peak specific gas production rate higher than the CSTR by a factor of 3.
2. Peak Methane production rate higher than the CSTR by a factor of 4.
3. Methane yield in liters per kg volatile solids twice that of the CSTR.
4. Total volatile solids reduction three times higher than the CSTR.
5. Total volatile Chemical Oxygen Demand Reduction three times better than the CSTR.

**Actual Outcomes:**

This prototype reactor system implementing the advanced process had the following measurable outcomes:

1. The specific gas production rate is 3.3 times higher than that for the CSTR.
2. The peak methane production rate is 3.9 times higher than that for the CSTR.
3. The methane yield in liters per kg volatile solids added is 1.88 higher than the CSTR.
4. The volatile solids reduction is 2.35 times more than for the CSTR.
5. The total Chemical Oxygen Demand Reduction is 3.35 better than for the CSTR.

**Conclusions:**

These results were developed by comparing the results of the tests of the two prototype units of identical volume, operated side by side at 20 degrees Centigrade. The Outcomes show that the prototype reactor system implementing the advanced process produces 1.88 times more methane per unit mass fed than the CSTR. All other figures of merit are also superior to those of the CSTR.

These results verify the feasibility of using the advanced hydrolysis and biogasification process for methane production thereby increasing wet biomass solids reduction. Overall, the advanced hydrolysis and biogasification process can convert organic solids to methane between two (2) and four (4) times faster (depending on loading) than a comparable CSTR unit. Most importantly, the total volatile solids reduction was 2.35 times more complete on the advanced hydrolysis and biogasification process than with CSTR. While this is less than the goal of three times improvement, it is nonetheless a significant improvement, because with the advanced hydrolysis and biogasification process nearly all the biomass feedstock is convertible to biogas (primarily methane), leaving little solid material for disposal.

It is important to note that while this experiment was performed at 20°C in order to slow the reaction for purposes of comparison between the advanced hydrolysis and biogasification process and CSTR, the optimal operating temperature for the mesophilic range is 35°C. The standard rule of thumb is that the reaction rates for these digesters would be about 2.5 times faster if operated at 35°C rather than at 20°C.

**Benefits to California:**

All large power plants being proposed for California rely on natural gas as the fuel. Most of that fuel is imported into the state. Biogas (predominately methane) can be produced from indigenous biomass material. The major sources of wet biomass waste produced in California are sewage sludge production, fiber production (pulp and paper), food processing, agriculture and animal wastes. These sources could generate over 45 million tons of wet biomass in California. If the advanced hydrolysis and biogasification process were to penetrate 100% of the Wastewater Treatment industry and 20% of the agriculture industry, that process would produce an estimated 1.54 billion therms of biogas (methane) gas per year for electrical generation or for process heat. Because of the existing capital investments in waste treatment, benefits would build over a period of 10 to 15 years. It is likely that investors would first build treatment facilities utilizing the advanced hydrolysis and biogasification process to handle concentrated sources of wet biomass waste. Once scrubbed of impurities, the biogas could be directly used in power plants.

In addition, the deployment of this process would reduce the environmental problems and expense associated with the disposal of large volumes of wet biomass solids.

**Recommendations:**

The testing completed on this project has assisted in identifying areas where additional development is needed. Areas for additional effort are:

- Demonstrate a commercial scale (sized 1 to 4 ton/day) agricultural prototype, and select a strategic partner to help with commercialization. Seriously evaluate the benefits of designing this prototype to be highway truck transportable.
- Evaluate methane production from new feed stocks to expand applications for the advanced hydrolysis and biogasification process.

**Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.



## Control of On-Off Equipment in Buildings

**EISG Grant Number:** 99-03

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** David Auslander (510) 642-4930

**Organization:** University of California, Berkeley

**Grant Amount:** \$75,000

**Status:** Completed

### Project Description:

Equipment used to control process variables such as temperature in buildings often operate by cycling on and off (or between stages if more than one “on” state) rather than as continuously modulating. Examples of such equipment include small to mid-sized packaged air-conditioning systems, furnaces, chillers operating at low loads, cooling tower fans, and some types of electrical heaters. On-off control units normally start and stop equipment when the process variable (e.g., space temperature) crosses a level. There are a number of disadvantages to using level-crossing logic. One disadvantage is that it is difficult to control the variation in the process variable with level-crossing logic, even if it is implemented digitally, because of the phase lag of the process. Another disadvantage is that level-crossing logic is not well suited for staged operation in which there exists more than one “on” state. A third disadvantage of level-crossing logic is that it makes the coordination of multiple units difficult.

This project developed and tested the feasibility of a new control strategy for the operation of “on-off” and staged equipment in buildings using computer simulation methods. Specifically, it developed the control logic so that it could be used to coordinate the operation of multiple units, and compared the performance of the new strategy with level-crossing logic. This technology was proposed as a means of reducing the energy consumption of HVAC equipment by reducing the frequency of start-stop operations. If the hourly start-stop cycling is reduced by two-thirds, the coefficient of performance of vapor compression equipment is raised an estimated 10%. The corresponding improvement for non-electric heating equipment efficiency is estimated at 6%.

This project applied pulse-width modulation (PWM) logic and a finite state machine to start and stop individual units. This control software was combined with a model of the heat transfer dynamics of a building and a transient model of HVAC equipment to study the performance of the new strategy and compare it to alternative strategies.

The metrics used to assess performance were energy consumption, peak demand, thermal comfort, and maintenance cost. The variability of the space temperature was used as a proxy for thermal comfort. Start-stop operations were used as a proxy for maintenance cost.

### Proposed Outcomes:

The goal of this project was to determine the feasibility of reducing the energy consumption of HVAC equipment by reducing the frequency of start-stop operations. This was to be achieved by use of a newly developed control logic to coordinate the operation of multiple HVAC sub-systems. The following project objectives were established:

1. Develop new control software for operating energy-intensive, on-off, or staged equipment in buildings by adapting existing concepts for designing pulse-width modulation logic and finite state machines to this application.
2. Perform a computer simulation analysis of the performance of the control software to determine whether or not the new control strategy has energy, thermal comfort, or maintenance benefits relative to existing methods of operating this equipment.

3. Assess the change in energy efficiency as a result of the change in start-stop operations of vapor compression equipment with a target of 13% improvement, and non-electric heating equipment with a target of 6% improvement.
4. Maintain occupant thermal comfort levels.

**Actual Outcomes:**

1. The control software development yielded code that could be used to operate a wide variety of staged HVAC equipment in buildings.
2. The computer simulations determined that the proposed control logic had no beneficial impact on overall energy consumption, thermal comfort or maintenance costs.
3. The new control logic increased the frequency of start and stop operations by 27%.
5. The new control logic increased the size of the deviation from the space temperature set point by 11%.
6. An unanticipated outcome was the discovery that the new control logic combined with an optimized coordinator could load-level the power consumption of HVAC equipment, reducing excursions by 20% relative to level-crossing logic.

**Conclusions:**

1. Commercialization would involve control software development. The existing code would have to be adapted to a particular platform, but no hardware would be required as long as there was an existing control communication system in place so that a coordinator running on a networked computer could supervise a number of HVAC control units.
2. Using the proposed metric for equipment efficiency, the 27% increase in frequency of start-stop operations corresponds to an estimated seven percent (7%) decrease in coefficient of performance of vapor compression equipment and a greater than one percent (1%) decrease in non-electric heating equipment efficiency.
3. Equipment manufacturers are sensitive to the increased warranty risks due to increased on-off cycling.
4. Equipment installers may be reluctant to utilize this control logic because weaker temperature and humidity control may result in decreased comfort levels.
5. For commercial businesses with high power consumption the cost of power consumed during peak generation periods is high. Using the software control logic developed by this project to level the demand load during peak periods may save on energy costs associated with exceeding a billing rate threshold but any savings may be offset by increased energy consumption, higher maintenance and lower thermal comfort.

**Benefits to California:**

This project proposed the benefit of increased HVAC equipment efficiency derived from reduced on-off cycling. It discovered that PWM control strategy did not achieve this desired result. While the feature of load leveling by PWM control is an interesting development of this study, it is unclear to what extent California might benefit from this secondary result.

**Recommendations:**

Additional work is needed to investigate whether or not it is possible to provide energy benefits from the new strategy and to reduce the maintenance penalty. It is possible that by operating the PWM signals asynchronously and at different frequencies the maintenance penalty could be reduced. Asynchronous operation may also yield additional energy benefits. Asynchronous operation would increase the complexity of the design of the control logic, though not necessarily the complexity of its implementation.

**Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

## Development of a Unique Gas Generator for a Non-Polluting Power Plant

**EISG Grant Number:** 99-20

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Roger Anderson (916) 635-1606

**Organization:** Clean Energy Systems, Inc.

**Grant Amount:** \$74,871

**Status:** Completed

### Project Description:

Clean Energy Systems, Inc. (CES, Sacramento, CA) has defined and is in the process of developing a fossil-fueled, zero-emission power generation system. The key to this system is the combustion of a relatively clean fuel with oxygen in the presence of recycled water in a unique gas generator that directly produces a high-temperature, high-pressure gas composed almost entirely of steam and CO<sub>2</sub>. Fuel for the system can come from a variety of fossil or biomass sources so long as it is composed almost entirely of the elements carbon (C), hydrogen (H), and oxygen (O). Oxygen is used to combust the fuel rather than air as in conventional systems thereby eliminating the formation of NO<sub>x</sub> and large a volume of noncondensable exhaust gases. The high-energy gases produced by the gas generator drive multistage turbines that, in turn, drive an electrical generator. Exhaust gases from the turbine go to a condenser where gaseous CO<sub>2</sub> is separated from liquid water. Most of the water is recovered, reheated and returned to the gas generator. Gaseous CO<sub>2</sub> leaving the condenser passes to a recovery system where it is conditioned as necessary for use in enhanced oil or coal-bed methane recovery operations, for commercial sales, or for sequestration.

The gas generator is one of two key components in the system and is the focus of this program. CES successfully demonstrated the gas generator in this project. A high temperature steam turbine is the other key component requiring development. It was not the subject of this study. The CES generation system can operate with conventional steam turbines, albeit at reduced thermal efficiency.

Data from this project is being used in the design of a 10 MWe gas generator that will be used in system development testing under a cooperative agreement between CES and the U.S. Department of Energy's National Energy Technology Laboratory (NETL). Lawrence Livermore National Laboratory in Livermore California is the site being proposed for the demonstration of the CES cycle. If this site is chosen, the research will include CO<sub>2</sub> sequestration in abandoned oil wells.

### Proposed Outcomes:

The goal of this project was to determine the feasibility of the CES gas generator element operating at commercial power generation conditions. While based on rocket engine technology, the gas generator for commercial power generation must operate on different fuels for longer periods of times. The following project objectives were established:

1. Develop, build and demonstrate a gas generator having a premixing injector element design. Operate the gas generator on pure oxygen and methane adding water for steam production. The methane and oxygen mixture is not used in rocket technology, nor is it used in conventional power generators.
2. Operate the gas generator stably and reliably for extended periods of time. Gas generators of this type typically do not run on methane fuel, nor do they run for extended periods of time.

3. Operate the gas generator at temperatures and pressures required for a power generator. Temperatures and pressures required for commercial power generation differ from those required for rocket propulsion.
4. Demonstrate reliable premixing of oxygen, water and methane. The test must provide a stable flame over long periods of time to achieve the zero emission goal.
5. Demonstrate time-temperature process control in cool-down modules to promote re-association of by-products, thereby creating a clean, two-species gas. To achieve the zero emission goal the gas generator must burn all of the methane fuel while not creating carbon monoxide.

**Actual Outcomes:**

Significant outcomes of the program and major test results are as follows:

1. A complete gas generator with a premixing injector element was designed, built and successfully operated on oxygen, methane, and de-ionized (D.I.) water. The tests were accomplished at the University of California, Davis campus. This test system is available for further research and demonstrations on other feeds.
2. The gas generator operated repeatedly, reliably, and stably. At the completion of the project it had experienced more than 75 starts with a total run time of more than 10 hours and one individual test duration of 48 minutes.
3. The gas generator operated at temperatures up to 2700°F (1480°C), pressures up to 300 psia (20 atm), and at several fuel-air ratios. These conditions allow the gas generator to generate steam for today's commercial steam turbines and for advanced high efficiency steam turbines.
4. The researchers demonstrated repeatable ignition and stable combustion of premixed oxygen, methane, and water.
5. The product gases from the gas generator are composed almost entirely of two gas species (steam and CO<sub>2</sub>) with only a minor amount of O<sub>2</sub> and a trace of CO. No hydrocarbons or other volatile organic compounds were detected. The concentration of CO in the product gases was found to correlate well with predicted values.

**Conclusions:**

This project experimentally established the "proof-of-principle" for a novel gas generator component of a new system for producing clean electrical power from fossil fuels. The gas generator, based on rocket engine technology, produces high-energy drive gases that feed into steam turbines. Significant system integration tasks remain. Integration of such a gas generator into a power generation system could provide a viable, economical approach to zero-emission power production from a wide variety of fossil or biomass fuel. Such a system could make the total recovery of CO<sub>2</sub> possible at an affordable cost and in a form suitable for enhanced recovery of oil or coal bed methane or for sequestration. This project demonstrates a technically feasible method for eliminating from power plants both atmospheric pollution and CO<sub>2</sub> which has been implicated in the global warming concern.

**Benefits to California:**

The project represents the early development of a zero-emission, fossil-fueled power plant using rocket engine derived combustion technology. When commercially viable these power plants will offer a zero emission alternative to fuel cells for clean power generation. If the produced carbon dioxide is used in enhanced oil recovery, California could gain additional proven oil reserves and the associated economic benefits.

### **Recommendations:**

The Program Administrator recommends that California government and environmental agencies support CES in the development of this technology. The next steps are the development of small-scale demonstrators, larger demonstrators, and establishment of a facility for zero emission research. Lawrence Livermore National Laboratory, (LLNL) is currently attempting to secure funding for such a research facility at Livermore, California. That project would demonstrate both the overall zero emission power plant concept and enhanced oil recovery using the CO<sub>2</sub> produced. CO<sub>2</sub> would be sequestered in the process. High temperature steam turbines represent the other technology advancement needed to commercialize the CES power system for widespread, economically attractive power production. At this time there are no high temperature steam turbines commercially available. The technology to build high temperature steam turbines exists in the rocket engine industry. Significant research and development must be accomplished to take that technology and reduce it to commercial products with long life. Research organizations should also fund bench-scale demonstrations using alternative fuels to verify that this technology can be applied to commercial grades of oxygen with virtually any fossil or biomass fuel.

### **Project Status**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

## High Efficiency Single Phase Air Conditioner

**EISG Grant Number:** 99-39

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Otto Smith (510) 525-9126

**Organization:** Smith & Sun

**Grant Amount:** \$75,000

**Status:** Completed

### Project Description:

Electric power system overloads often occur during hot summer afternoons when many residential air conditioners are operating. The majority of these air conditioners are powered by single-phase electric motors. Out of concern for power reliability on these hot afternoons, power companies bring on-line their least desirable power supplies. These are the most expensive to operate, the most polluting or oldest generators. These actions are taken to minimize the probability of system degradation or a blackout. The cost to the power company and to society to supply these air conditioners at the peak load time is high, and is often higher than the rate that the customer is currently paying. Also, emissions from the older power plants are usually higher than the newer power plants. The less desirable power plants would be dispatched less frequently if higher efficiency air conditioners were widely deployed in the marketplace at reasonable prices.

One solution is to power the air conditioners with the more efficient three phase motors. The constraint is that most residences and perhaps 40% of all rural areas have only single-phase power available, and it is uneconomic to change these distribution and wiring systems. The compressors are well designed, but the low efficiency single-phase motors on the compressor shafts are much less efficient than three phase motors of the same power rating.

This project demonstrated the feasibility of using a control system that can operate high efficiency three-phase induction motors from single-phase power supplies. These control systems were originally developed for water pumping applications by the researcher in previous, unrelated efforts. These controls are trademarked under the name Enabler<sup>TM</sup>.

The use of such controls on three phase air conditioner motors could reduce the electrical power demanded by residential and small commercial air conditioners by 8 to 10 percent. Air conditioner manufacturers would design all products with three phase motors, adding the control system to those sold to market segments where three phase power is not available.

### Proposed Outcomes:

The goal of this project was to determine the feasibility of operating air conditioners with three phase motors efficiently on single-phase power. A test program to measure efficiency was very carefully designed and implemented in order to provide high confidence in the test results. The following project objectives were established:

1. Design, construct and demonstrate a control system specifically for three-phase air conditioner motors enabling them to run using single-phase power.
2. Demonstrate that residential size central air conditioning units, running on three-phase motors that have been modified with a control system to operate on single-phase power, will consume 10% less electrical energy than equivalent air conditioning units running on single-phase motors.



**Actual Outcomes:**

1. Control systems were designed and constructed to operate two different three-phase motors from single-phase power. One motor was designated a Model 48T motor, the other, a Model 42T motor. The control systems were capable of operating the three-phase motors. As expected, motor performance was improved. With the control installed on the Model 48T motor, the winding current unbalance was reduced to only one percent, compared to 7.4% with the three-phase power supply. Also, the single-phase input to the control had a power factor of 90.8% LEADING, compared to 75.2% lagging with the three-phase power. With the control installed on the Model 42T motor, the winding current unbalance was reduced to 3.2%, compared to an unexpectedly large 13.8% with the three-phase power supply. Still, the single-phase input to the control had a power factor of 88.3% LEADING, compared to 77% lagging with the three-phase power.
2. All of the objectives were achieved for the two sizes of compressors that were tested. A 48,000 BTU/hour compressor and a 42,000 BTU/hour compressor were tested at an independent commercial testing facility by the professional staff as directed by Dr. Smith. Many tests were conducted. The average Energy Efficiency Ratio (EER) for each configuration is tabulated below, the efficiency improvement is presented in the last row:

| <b>Motor Configuration</b>                                    | <b>42,000 BTU/hour Unit</b> | <b>48,000 BTU/hour Unit</b> |
|---|-----------------------------|-----------------------------|
| <b>Three-Phase powered three-phase motor</b>                  | 10.816 BTU/Watt-hour        | 12.436 BTU/Watt-hour        |
| <b>Single Phase motor</b>                                     | 10.864 BTU/Watt-hour        | 10.691 BTU/Watt-hour        |
| <b>Enabler™ controlled single phase powered 3-phase motor</b> | 11.294 BTU/Watt-hour        | 11.950 BTU/Watt-hour        |
| <b>Improvement in Single Phase Powered Energy Efficiency</b>  | <b>3.958 %</b>              | <b>11.776%</b>              |

**Conclusions:**

The feasibility of operating three-phase motors in air conditioners using single-phase power was demonstrated. The motor performance improvement was consistent with that observed in prior development of the controls on larger motors. Without test results from additional like units, it can not be assumed that the savings of nearly 12 % of the electricity use for the 48,000 BTU/HOUR unit with the control system will be realized on all air conditioners of this size. The 42,000 BTU/HOUR unit demonstrated nearly a 4% energy savings. The test results show that the 42T three-phase motor was significantly below average in efficiency. It was less efficient than the single phase motor. The principal investigator concluded that this resulted from low quality in the area of winding current imbalance and suggested that a motor of average quality of this size would have produced greater efficiency gains. Due to the small sample size and variability in motor quality the Program Administrator estimates the energy savings from this invention to be in the 8% to 10% range on average, but additional testing will be needed to confirm this conclusion. The impact of the tested technology on unit efficiency was significantly effected by motor quality. That quality remains an unquantified variable. If the two three-phase motors selected in this study are representative of the range in quality of commercially available three-phase motors this would suggest that the motor manufacturing industry has a quality control problem that also needs addressing.

The ultimate commercial success of the Enabler™ technology will depend on the impact this technology will have on the retail cost of new air conditioners. The researcher reported that his



direct cost for the control system components (purchased at retail) was \$128 per unit. The researcher projected that the equipment manufacturers could reduce the direct cost of the control system circuitry to \$64 per unit if mass-produced. Based on the \$64 cost estimate, the Project Administrator projects an increase of about \$100 in retail price per unit of the large 48T class of air conditioner. The control circuit for the smaller units, utilizing smaller capacitors, would have a lesser retail price impact. To put this into perspective, the Program Administrator prepared a simple payback analysis. Two electric rates, \$0.10 and \$0.25 per KWH, were used to span a broad range of retail prices. The 48T motor tested uses electricity at the rate of 4 KW. By using the new control circuit, one could reduce demand by 10% or 400 Watts. It follows that the modified air conditioner would save 400 KWH in 1000 hours and 1000 KWH after 2500 hours of operation. A person with an electric rate of \$0.10/KWH will have a simple payback in 2500 hours of operation, while a person with a \$0.25/KWH rate will achieve a simple payback in 1000 hours of operation. Depending on the length of the cooling season, payback could occur in one to two cooling seasons. This supports the conclusion that this innovation offers a near term payback to the ratepayer using this control technology with three phase motors.

The researcher asserts that the direct cost of the control system circuitry could be further reduced if the manufacturers of the three-phase motors made some minor design modifications to the motor wiring. While additional research is required to bring this technology to market, air conditioner manufacturers would be able to adopt this new technology without modifying their existing manufacturing tooling.

### **Benefits to California:**

The primary benefit to California will be the availability of higher efficiency (8-10%) air conditioners to electric consumers that are limited to single-phase power. A second major benefit is the reduction in peak loading of the electrical system on hot summer days. Many advantages accrue to the ratepayers from the reduction in peak loads. The relatively near term availability of these benefits is due to the simple, modular nature of the control circuitry, which can be a simple add-on at first, with integration in depth developed as cost cutting measures by the manufacturers.

### **Recommendations:**

The results of this project indicate that significant energy demand reductions can be accomplished in the relatively near term if the tested technology is deployed in California. Because of the limited funds in the grant, the researcher only tested the control system on two air conditioning compressor units. To further this technology, additional testing is needed to assess the energy savings on a full range of commercially available air conditioning units. Research is also needed to fully define the distribution of motor quality to enable a more accurate projection of average efficiency improvement. In addition, the researcher should select a major manufacturer of air-conditioners as a partner in any additional research to insure that the technology development meets all market needs.

### **Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

## Renewable Hydrogen Fuel Production by Microalgal Photosynthesis

**EISG Grant Number:** 99-06

**PIER Area:** Renewables

**Principal Investigator:** Anastasios Melis (510) 642-8166

**Organization:** University of California, Berkeley

**Grant Amount:** \$75,000

**Status:** Completed

### Project Description:

The ability of unicellular green algae to produce hydrogen ( $H_2$ ) gas in the presence of sunlight has been recognized by the scientific community as being a possible way to generate hydrogen gas for energy production. Below is a list of important known factors specific to green algal  $H_2$  production.

1. Photosynthesis can operate with a photon conversion efficiency of  $>80\%$ .
2. Microalgae can produce  $H_2$  photosynthetically with a photon conversion efficiency of  $>80\%$ .
3. Molecular Oxygen ( $O_2$ ) acts as a switch by which  $H_2$  production is turned off.
4. Sixty years of research has failed to overcome the incompatibility of simultaneous  $O_2$  and  $H_2$  production by photosynthesis.

Recent work has shown that the absence of Sulfur (S) from the growth medium of the green algae *Chlamydomonas reinhardtii* (*C. reinhardtii*) causes a specific but reversible decline in the rate of oxygenic photosynthesis but does not affect the rate of mitochondrial respiration. The absence of sulfur from the growth medium triggers a metabolic switch, one that selectively and reversibly turns-off photosynthetic  $O_2$  production. In the presence of S, green algae photosynthesize normally ( $H_2O$  oxidation,  $O_2$  evolution and biomass accumulation), however, in the absence of S and absence of  $O_2$ , photosynthesis in *C. reinhardtii* produces  $H_2$  rather than  $O_2$ . Further refinement of this method may lead to full understanding of the green algae hydrogenrelated metabolism and ultimately the generation of  $H_2$  gas for the fuel and chemical industries.

### Proposed Outcomes:

The goal of this project was to determine the feasibility doubling the hydrogen production efficiency of *C. reinhardtii* from the level of  $\sim 10\%$  of the theoretical maximum to the level of  $\sim 20\%$  of the theoretical maximum. The following project objectives were established:

1. Improve the  $H_2$  production by shifting forward the equilibrium of the reversible hydrogenase catalyzed reaction.
2. Design and test cell growth media that accentuate the metabolism of  $H_2$  production.
3. Test the effect of diurnal cycles on starch mobilization and  $H_2$  production.
4. Identify the rate-limiting step in the  $H_2$  production process.

### Actual Outcomes:

1. Two approaches were investigated attempting to shift forward the equilibrium of the reversible hydrogenase catalyzed reaction:
  - a. The atmospheric air within the photobioreactor was purged with argon to remove dissolved  $O_2$  prior to initiation of  $H_2$  production. Independent measurements have shown that such degassing is sufficient to reduce the  $O_2$  content of the culture to less than 2% of saturation. This purge resulted in almost immediate initiation of  $H_2$  production, while  $H_2$  production by the control culture was delayed for another 10 to 15 hours, hence this approach shifted the reaction forward, reducing the wait time by roughly 10-15% of the hydrogen production cycle length.

- b. The pH balance of the water in the gas collection device was modified with the thesis that the water was saturated with H<sub>2</sub> gas and perhaps contained a significant amount. No detectable increase in the collected amount of H<sub>2</sub> gas was observed.
2. Multiple designs of cell growth media were tested to accentuate the metabolism of H<sub>2</sub> production.
  - a. Determined the effects of salinity:
    - i. On chlorophyll content and cell viability. Cell density increased then remained constant with moderate levels of salinity.
    - ii. On cellular photosynthesis and respiration. Neither photosynthesis nor respiration appeared to be effected by reasonable amounts of salinity.
    - iii. On H<sub>2</sub> production. A moderate level of salinity, 10 mM NaCl enhanced the rate and yield of H<sub>2</sub> gas by 30% and 40% respectively over the control.
  - b. Determined the effects of ATP biosynthesis uncouplers as follows:
    - i. Methylamine-hydrochloride. Over a very narrow range centered on 5 mM Methylamine, H<sub>2</sub> production increased as much as 20-25% over the control.
    - ii. Gramicidin. This chemical was not sufficiently soluble to allow investigation of concentrations greater than about 5 micromoles. However, at that level the effect was similar to that of Methylamine, above.
    - iii. FCCP. This chemical significantly reduced the production of H<sub>2</sub>.
  - c. Determined the effect of trace amounts of S; Used 10, 50 and 100 micromoles S samples. The addition of S was observed to delay the onset of H<sub>2</sub> production. However the total production increased with increase of S until the delay of onset became the dominant factor. Culture with 50 micromoles S added produced about 35% greater H<sub>2</sub> yield than produced by the cultures with no S added.
3. The *C reinhardtii* were cyclically deprived of S and supplied with S, for three complete cycles, and the rate of production of H<sub>2</sub> was recorded. The result was that the single culture of *C reinhardtii* produced about three times as much H<sub>2</sub> in three cycles as the control cultures did in a single cycle. This illustrated the capacity of the *C. reinhardtii* to recover from the catabolic effects of H<sub>2</sub> production when S is provided between H<sub>2</sub> production cycles.
4. The rate limiting step in the H<sub>2</sub> production process was identified by Western Blot analysis of the total cell protein extracts from *C reinhardtii*. This showed that the hydrogenase gene is expressed sparingly under S deprivation conditions.
5. In all cases the gas produced by the *C reinhardtii* algae was collected in a tube (upside down burette) filled with water. The gas collected in this manner was reported as hydrogen. Gas chromatographic analysis of the gas collected showed ~90% H<sub>2</sub>, ~10% nitrogen with traces of CO<sub>2</sub> and O<sub>2</sub>.

### Conclusions:

This research indicates that H<sub>2</sub> production rates approaching 20% of theoretical maximum could be achieved by proper combination of the techniques explored in this project.

1. The equilibrium of the reversible hydrogenase catalyzed reaction can be shifted forward.
  - a. There is significant benefit, 8 - 12% production improvement to be gained by rapid transition from aerobic to anaerobic environment in the photobioreactor medium, compared to a "natural" transition.
  - b. The question of H<sub>2</sub> solubility in water was not definitively answered.
2. H<sub>2</sub> production can be increased by improving the design of the cell growth media.
  - a. Moderate levels of salinity of the culture do not adversely affect cell viability and do increase H<sub>2</sub> production by ~40%. However, there may still be room for improvement with further study.

- b. Due to the modest effect and the high cost of ATP biosynthesis inhibitors, their use is not the method of choice for manipulation of H<sub>2</sub> production.
- c. Sulfur titration holds the promise of improving the yield of H<sub>2</sub> production by as much as 35% in this two-stage photosynthesis and H<sub>2</sub> production method. Its utility in a production environment is a concern.
3. It may be possible to extend the production of H<sub>2</sub> by a single culture ad infinitum by alternately supplementing and depriving the culture of its organic sulfur. Three cycles were demonstrated.
4. The sparse expression of the hydrogenase gene within the *C reinhardtii* is responsible for the limited H<sub>2</sub> production. Genetic engineering should be applied to increase the expression of this gene.
5. The technique for removal of nitrogen from the product gas must be identified.
6. It is evident that incremental improvements in the yield of hydrogen production can be accrued upon R&D of the method. However, further improvements need to be achieved to make "hydrogen production by sulfur-deprivation of green algae" a commercial reality.

**Benefits to California:**

Both small-scale (industrial and commercial) and larger (utility) solar energy conversion plants (photobioreactors) can be envisioned utilizing the Two-Stage Photosynthesis and H<sub>2</sub>-Production process. Remote photobioreactors could be installed as modules in arid areas where sunlight is plentiful and alternative uses of land are minimal. Such a process of H<sub>2</sub> gas production would be sustainable, environmentally friendly and economically attractive compared to most other hydrogen production alternatives.

In addition to H<sub>2</sub>, a valuable and clean fuel, the Two-Stage Photosynthesis and H<sub>2</sub> -Production process will generate green algal biomass as a significant "Value-Added Bioproduct" that will enhance the economics and competitiveness of the process.

**Recommendations:**

Further Research and development should address the specific biological and engineering challenges facing commercialization of this technology.

- Further basic research should be done to improve understanding of the cellular metabolism and basic biochemistry that support this process.
- This project demonstrated that hydrogen production of 20% of theoretical is achievable, however, further research should be done to improve the hydrogen production further.
- Preliminary designs for the scale-up of the process should be created, and a preliminary life cycle cost analysis performed. This analysis should compare the cost of producing electricity by this method to the cost of PV. Further, this analysis should compare the cost of producing hydrogen by this method compared to the electrolysis method.

The technology developed in this project will take 8 to 12 years to advance to the state of market readiness.

**Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

## Ventilation Measurement and Control

**EISG Grant Number:** 99-02

**PIER Area:** Buildings End-Use Energy Efficiency

**Principal Investigator:** Clifford Federspiel (510) 418-3392

**Organization:** Federspiel Controls

**Grant Amount:** \$74,970

**Status:** Completed

### Project Description:

Cost-effective and accurately-measured airflow rates, especially at outdoor air intake locations, are a recognized difficulty with ventilation controls. Typically, outdoor air intakes have no ductwork either upstream or downstream. The most common configuration is a set of dampers mounted in a large opening of a mixing plenum. This configuration can cause large non-uniformities in the velocity distribution. Existing airflow measurement technology is not effective with non-uniform airflow. Since outdoor airflow rates cannot be measured accurately or cost-effectively, ventilation systems are routinely operated without knowing ventilation rates, and other key airflow variables. The result is wasted energy or compromised air quality, or in some cases both.

The purpose of this project was to develop an energy-efficient, cost-effective, accurate, and maintenance-free flow measurement and control technique for ventilation systems. This program has a specific technical goal: airflow measurement accuracy of  $\pm 10\%$  of actual or  $\pm 5\%$  of full scale, whichever is greater. This criterion is derived from an addendum to ASHRAE Standard 62.1. Broader goals included a controller design that requires less maintenance than current technology at lower first cost.

The researchers proposed to use torque characteristics of control dampers to measure flow. They theorized that if the position and aerodynamic torque were measured, then it should be possible to deduce the flow rate. The hypothesis is that torque-based flow measurement (TBFM) should be accurate at low velocities if the damper is constructed to induce aerodynamic torque when throttling. The TBFM should also be insensitive to non-uniform flow because the entire surface of the damper blades is used as the sensing means.

### Proposed Outcomes:

The goal of this project was to determine the feasibility of the TBFM technique as a cost effective ventilation airflow measurement device with an accuracy of  $\pm 10\%$  of actual flow or  $\pm 5\%$  of full scale, whichever is greater. The following project objectives were established.

1. Develop a correlation function (mathematical model) that accurately describes the relationship between the position, aerodynamic torque, and air velocity of control dampers.
2. Perform a computer-based sensitivity analysis using the correlation function. Determine whether or not the goal of  $\pm 10\%$  of actual flow or  $\pm 5\%$  of full scale can be achieved given typical torque and position measurement errors.
3. Design and construct a prototype flow measurement device and test stand based on the results of the modeling and sensitivity analysis.
4. Demonstrate an accuracy in airflow measurement of  $\pm 10\%$  of actual flow or  $\pm 5\%$  of full scale, whichever is greater.
5. Achieve a cost effective design that requires less maintenance than current technology.
6. Assess the accuracy of TBFM in the presence of flow disturbances.

**Actual Outcomes:**

1. Existing theories on the torque characteristics of butterfly valves were combined with published experimental results to formulate a model that predicts the torque characteristics of multi-blade control dampers. The development of the correlation function demonstrated that the relationship between position, torque, and airflow has a simplified form that makes calibration of the correlation function relatively simple. The correlation function predicts that the velocity is the product of a function of the position and a function of the torque.
2. The sensitivity analysis predicted that the technical goal could not be achieved when the damper was nearly open, but it should be easily achievable for the most important operating conditions. The most important operating condition is when the damper is about 10% - 20% open because that is the range of conditions for controlling minimum ventilation. Under that condition, the sensitivity analysis predicted that the technical goal could be achieved, and that the torque-based flow measurement should significantly outperform a pitot tube or similar flow measurement technology.
3. A test stand was constructed that used five high-accuracy pitot tubes in a constricted duct as a measurement standard. A prototype flow measurement device with an offset-blade design was constructed. The offset-blade design uses standoffs to make the damper blades rotate about an axis that is displaced by two inches. This design induces torque even when the damper is fully open.
4. The laboratory-scale tests confirmed the results of the sensitivity analysis. The tests showed that when nearly open, the torque was very low even with the offset-blade damper.
5. To provide a more cost effective device, the flow measurement device was designed without pitot tubes. This eliminated the recurring maintenance task of verifying that the air passages are clear of dust.
6. Tests were conducted to assess the ability of the TBFM technology to operate accurately in the presence of a flow disturbance. To simulate a disturbance, a commercially available louver was mounted to the frame of the TBFM prototype and to the frame of the commercially available flow station. These tests illustrated that the TBFM technology is insensitive to the flow disturbance when the damper is less than 70% open. When the TBFM damper is more than 70% open, the flow disturbance has a significant negative impact on the accuracy.

**Conclusions:**

1. The TBFM technology can outperform conventional flow measurement technology under a wide range of operating conditions. The TBFM technology is more accurate than a pitot tube when the damper is less than 80% open. This project found that the TBFM technology is insensitive to the presence of a significant upstream flow disturbance when the damper is less than 70% open. The accuracy of a commercially available airflow station was strongly affected by the presence of the same upstream disturbance.
2. The fact that the TBFM technology cannot provide accurate measurement of velocity when the damper is nearly open is a problem for a small percentage of applications.
3. One significant obstacle to commercialization of the TBFM technology is that it cannot be used in the retrofit market because of the expense of retrofitting dampers. Some dampers are embedded in HVAC units, and can only be replaced by dismantling the HVAC equipment. The researcher contacted a manager from a leading energy service company (ESCO) to get an opinion on the commercial viability of the TBFM. The manager told the researcher that his company would have no interest in the TBFM technology because of the cost of retrofitting dampers.



4. A significant obstacle to commercialization of the TBFM technology in the new construction market is that it requires substantial change in the way damper devices are designed and manufactured. In order to get the full benefit, the damper design would have to be changed to an offset-blade design with low-friction bearings, which would involve some re-tooling for an equipment manufacturer.

**Benefits to California:**

If the TBFM technology were widely used, California would benefit from reduced energy consumption, reduced peak demand, and improved productivity and health. Energy consumption and peak demand would be reduced because the technology would prevent over-ventilation and enable demand-controlled ventilation. Fisk and Rosenfeld (1997) estimate that improvements in indoor air quality could save \$12 - 43 billion nationally in lost productivity due to health problems in buildings. The developed technology, if implemented could recover some of that lost productivity by providing better ventilation at a lower energy cost. This would be one step toward improved indoor air quality.

**Recommendations:**

Follow-on development should focus on the design and cost of the damper system so that this technology could be applied to the new construction market. In addition future work should attempt to improve the measurement accuracy when the dampers are nearly open.

The developers of this technology should work closely with potential manufacturers. Before pursuing follow-on technical effort, the developers should achieve positive indications of interest and support for this technology from members of the HVAC industry. Minimum levels of support would include the provision of acceptable end item cost targets and desired technical specifications.

The awardee has presented a number of technical approaches to resolve the implementation difficulties. These could be pursued once the interest of the industry and the market requirement specifications are established.

**Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

# EISG Projects Completed in 2001



## Electrosynthesis of Device Quality Semiconductor Films

EISG Grant Number: **99-01**

**PIER Area:** Renewables

**Principal Investigator:** Shalini Menezes (805) 497-2677

**Organization:** InterPhases Research

**Grant amount:** \$75,000

**Status:** Active

### Project Description:

This project devised a Copper Indium Diselenide (CIS) deposition method that is simpler, less expensive, and more effective than the prevailing methods. The *Electrochemical Molecular Layer Epitaxy* (EMLE) method was developed in order to simplify the synthesis of electronic grade CIS films and reduce fabrication costs for large photovoltaic (PV) modules. The project targeted the energy problem of reducing the capital equipment cost for photovoltaic (PV) modules production in order to make the cost of PV power systems competitive for California ratepayers. It developed this new non-vacuum approach to fabricate high quality thin-film materials for PV modules that could lower the manufacturing costs by over 50% and increase the PV module efficiencies.

The project addressed the PIER subject area of Renewable Energy Technologies. Within that field, this project addresses the cost of manufacturing solar photovoltaic (PV) systems. Worldwide PV markets have been expanding, with sales projected to exceed \$12 billion by 2010. PV could provide a large portion of the state's electricity needs without negative impact to the environment, but this potential is limited due to the high initial cost of PV systems. In order to mitigate costs, subsidized buy-down programs have been introduced so that PV power can compete in the current energy market.

This EISG project explored a means to manufacture PV devices at lower cost. It created a nonvacuum fabrication method, specifically targeting the commercially important Copper Indium Diselenide (CIS) PV cell. CIS technology is important because when fabricated with complex, expensive laboratory scale vacuum methods, CIS cells are more reliable and efficient relative to other thin film PV types. Unfortunately, currently existing low-cost non-vacuum methods, suitable for large-area cell manufacturing result in low-grade films, which require further costintensive vapor phase treatments. The *Electrochemical Molecular Layer Epitaxy* method integrates the low-cost, large area features of electrodeposition with the atomic level, or nanoscale control of vapor phase epitaxial methods to produce high quality CIS films at ambient conditions from aqueous solutions. The project impacts both the positively doped CIS (*p*-CIS) state of the art solar cell, as well as the new flexible, lower cost negatively doped CIS (*n*-CIS) solar cell being developed.

### Proposed Outcomes:

1. Design, assemble and test new apparatus and control software for nanoscale-controlled electrodeposition that eliminates need for vacuum processing.
2. Identify critical deposition parameters.
3. Synthesize binary precursor films.
4. Analyze the thin-films with electrochemical and surface analytical characterization.
5. Extend the investigation to produce ternary CIS absorber layer.
6. Begin a process of commercial readiness.

**Actual Outcomes:**

1. A new non-vacuum electrodeposition apparatus, including process control software, was successfully designed, assembled and tested. The introduction of an unconventional thin layer flow cell was the key element that facilitated a precise electrodeposition process.
2. The effects of the standard EMLE deposition parameters of temperature, electrolyte composition, deposition potential, and timing parameters were identified, along with the effect of electrolyte volume.
3. The CuSe superlattice films (binary precursor films) were grown using three different methods, which enabled the identification of the process parameters.
4. A series of samples comprising 500-800 layers deposited on Mo/glass were analyzed and their composition determined. Film composition was tabulated as a function of the process parameter values.
5. This project led to a new method to produce a commercially valuable ternary CIS film, CuInSe<sub>2</sub>. The results offer valuable insights into the role of process parameters allowing the identification of a new means to incorporate less noble metals in CIS film as required for high efficiency PV cells.
7. A US Patent was granted on May 8, 2001, based on the concepts underlying the new method.

**Conclusions:**

While a fully functioning production line is still five years away, this project advanced the science toward using non-vacuum, electro-deposition for the production of thin film CIS PV cells.

1. The new electrodeposition apparatus and methodology represents an important advancement in electro-deposition process technology. It could allow the substitution of inexpensive electro-deposition hardware for the expensive vacuum deposition processing hardware currently needed to produce CIS thin film PV. Major gains were made in fine control of the electro-deposition process.
2. The new electrodeposition methodology, applied to the task of producing CIS thin film PV, has the potential to eliminate vacuum processing, reduce processing temperature, eliminate the need for multiple electrolytes, and eliminate the need for post annealing step. These potential advantages must be demonstrated in a subsequent development phase.
3. The original objective of this project was to produce a binary precursor film of CuSe using the new EMLE process, however, early success in producing the binary film allowed for the project to be extended to include the successful fabrication of a ternary Cu-In-Se material that constitutes the solar cell absorber layer.
4. Characterization of the fabricated binary and ternary samples confirmed the feasibility of the deposition process to produce high quality layers. This result should support the fabrication of CIS PV films with conversion efficiencies comparable to films produced using the existing expensive process.
5. The results of this research support the conclusion that through the commercialization of the new electrodeposition apparatus and methodology that the fabrication cost of electronic grade CIS films could be reduced by at least 50% for large PV modules.

This EISG project has been timely and instrumental in launching an alternate thin film deposition technology with the potential for lower manufacturing cost. The research team learned how to provide fine control of the electro-deposition process. The EMLE method compares well against other low-cost methods for CIS deposition that are being developed for the current *p*-CIS solar cell, as well as for a new flexible, lower cost *n*-CIS solar-cell. Nearly all other methods need an expensive, hazardous high-temperature selenization second step to produce device quality CIS

films. The results are particularly important for the production of low-cost, high-volume flexible solar cells, based on *n*-CIS technology.

Further, the results of this project include a new process representing entry into the field of nanotechnology. This approach of electrodeposition controlled at the atomic level presents a relatively simple, rapid and inexpensive process to create a broad spectrum of complex semiconductor superlattices, heterostructures and quantum well devices. The new findings and their anticipated contribution to photovoltaics and nanotechnology are very important.

**Benefits to California:**

The project performed R&D on technology that holds many potential benefits to California electricity ratepayers and the state economy. The project technology has the potential to:

1. Provide California ratepayers with a viable cost-effective PV technology.
2. Realize an affordable, reliable, state-of-the-art, clean and safe renewable energy resource for California residents.
3. Provide a timely cost-effective renewable energy option for distributed generation to California utilities and ensure energy diversity, quality and reliability in the electricity markets.
4. Lead to new in-state jobs and higher tax revenues, thus boosting California's vitality and the overall economy.
5. Provide a new developmental entry into the high potential nanotechnology field.

**Recommendations:**

The success of the feasibility study warrants further development of the new deposition method to fabricate a complete solar cell. The next stage will advance the project to:

1. Extend the functionality of the design, build and test a prototype deposition apparatus and control system suitable for use in fabrication of a complete *n*-CIS solar cell.
2. Advance the EMLE process to optimize the methodology for depositing all components of *n*-CIS PV cells.
3. Automate the equipment and process and produce a quantity of *n*-CIS PV cells for operational evaluation and analysis.
4. Because there currently exists a complete infrastructure supporting the manufacture and distribution of the positively doped CIS (*p*-CIS) PV cell, it is also recommended that this project advance the process to synthesize the components of *p*-CIS PV cells.
5. Develop a preliminary production readiness plan to produce commercially viable PV module manufacturing equipment.

The EISG project results provide the bases and the directions for future R&D to fabricate a complete PV device. The method will evolve into an inexpensive, integrated system for large scale manufacturing of efficient PV modules. The scale-up will take advantage of the existing automation and process lines designed for the electroplating industry. The final process will be user-friendly, robust and readily amenable to scale-up for mass production of PV modules.

**Project Status:**

- 100 % Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.

## **Improved Operational Turndown of an Ultra-Low Emission Gas Turbine Combustor**

EISG Grant Number: **99-13**

**PIER Area:** Environmentally Preferred Advanced Generation

**Principal Investigator:** Scott Smith (408) 727-8282

**Organization:** Alzeta Corporation

**Grant Amount:** \$74,103

**Status:** Completed

### **Project Description:**

Alzeta Corporation is a manufacturer of industrial burners and combustion systems. Alzeta is developing an advanced low-emissions combustor for use in industrial gas turbines and microturbines. Alzeta's goal is to develop a low emissions combustor that is effective, relatively low cost and can be designed to fit into most existing gas turbine engines. The final report (see Appendix A) details design and testing of Alzeta's Gas Turbine Surface Burner (GTSB). Testing was accomplished at atmospheric conditions and in Honeywell's 75 kilowatt combustor test rig.

In California's changing electricity market, small gas turbine generators may be playing an increasingly important role. These units hold the promise of bringing cheaper, more reliable electricity to California's ratepayers. To reduce harmful air emissions, these units must be equipped with combustors that reduce the oxides of nitrogen to less than 5 ppm. Alzeta's GTSB is being developed to address emissions reduction to these levels without significantly increasing capital equipment costs.

The low-emissions performance of the GTSB derives from its ability to stabilize combustion at low adiabatic flame temperatures where side reactions responsible for NOX formation are thermodynamically less favorable than complete combustion of hydrocarbon fuel. To reduce the adiabatic flame temperature, more air than necessary for complete combustion is premixed with gaseous fuel and directed through the combustor. In the gas turbine industry, this approach is called lean-premixed, dry low-NOX (DLN) combustion. The GTSB differs from existing DLN systems. Its stabilization mechanism removes heat from the combustion reactions by radiant heat transfer resulting in lower NOX formation than attainable by well-stirred premixed combustion with the same amount of excess air.

A potential barrier to commercialization of the GTSB, as with other DLN systems, is the problem of operational turndown. It is difficult for DLN systems to sustain combustion when the power level is reduced from full power to levels as low as 50% power. Increasing the operational turndown of the GTSB requires precise local control of the air-fuel ratio over selected regions of the burner surface. This level of control can be accomplished by partitioning the GTSB into independent segments. Under low fuel-flow conditions, the air-fuel ratio can be maintained in an individual segment while fuel-free air passes through adjoining ones. The number and size of the segments can be adjusted to provide stable combustion over the load range. At full load, the entire GTSB is fired with fuel divided among its segments such that each is operated at the same air-fuel ratio.

### **Proposed Outcomes:**

The goal of this project was to determine the feasibility of a segmented GTSB. Alzeta's strategy is to develop a low emissions gas turbine combustor that is effective, relatively low cost, adaptable to existing engines, and has the flexibility to operate over a broad engine turndown ratio. This project's focus is on increasing the operational turndown ratio of the GTSB while

maintaining low emissions over the load range. Alzeta partitioned the burner into segments to achieve this result. They planned to add a fuel-air mixture to the segments in a sequential manner as engine load increased. To be successful, the segmented GTSB had to meet emissions targets of sub-5 ppm NOX (referenced to 15% O<sub>2</sub>), sub-10 ppm CO and sub-10 ppm unburned hydrocarbons over the operating range of a micro-turbine engine. The following project objectives were established:

1. Provide three conceptual designs of segmented GTSB. The designs should be differentiated by geometry and number of segments. Create criteria to identify and select the most promising design. Produce design drawings for a GTSB that will fit into the Honeywell 75 kWe combustor test rig.
2. Build and instrument the test combustor. This design objective is important because a segmented GTSB is a new concept and has not been previously designed for testing at gas turbine conditions.
3. Test the segmented GTSB at atmospheric conditions. Measure combustor emissions at six engine-operating conditions from idle to full power. Vary the fuel flow split to the segments at each operating condition to optimize emissions. Measure and record NOX and CO emissions at each operating condition and each segmented fuel flow condition. The objective is to prove the capability of the segmented GTSB to achieve NOX emissions less than 5 ppm at atmospheric pressure over simulated engine operating conditions. This atmospheric pressure test, while less rigorous than Objective 4, provides relatively low cost data to the designers early in the development cycle so that adjustments can be quickly and easily made.
4. Test the segmented GTSB at pressures typical of the Honeywell 75 kilowatt Parallon engine. Measure combustor emissions at six engine-operating conditions from idle to full power. Vary the fuel flow split to the segments at each operating condition to optimize emissions. Measure and record NOX and CO emissions at each engine condition and each segmented fuel flow condition. The Honeywell engine operates at conditions typical of most microturbines. Gas turbine emissions often increase with increasing engine pressures. Testing at simulated engine pressures provides information about the pressure sensitivity of the emissions from a combustor without developing a full engine test.

### **Actual Outcomes:**

1. Three GTSB concepts were evaluated. A two-segment GTSB was selected based on ease of fabrication, control system integration and the effect of internal baffles on air-fuel mixing. Alzeta engineers designed the selected GTSB concept to mate with both the Alzeta test facility and Honeywell's test facility for the Parallon 75 micro-turbine.
2. The GTSB was fabricated. The test GTSB was instrumented with thermocouples and gas sample lines. No unusual problems were encountered.
3. The segmented GTSB was tested at atmospheric conditions at the Alzeta test facility. It was operated stably at six conditions that simulated engine power conditions from idle to full power. The NOX emissions were less than 5 ppm (adjusted to 15% oxygen) and CO emissions were less than 10 ppm. The fuel flow split between the two segments was adjusted at each operating condition to optimize the emissions.
4. The segmented GTSB for the Parallon 75 was fabricated and installed in the pressurized test facility at Honeywell. Testing of the segmented GTSB was accomplished at five of the six planned engine conditions. The selected set points were established in terms of air flow through the GTSB. These points were: 13.6 pounds per hour (pph), 18.5 pph, 24.7 pph, 30.8 pph, 37 pph, and 41.6 pph (full power). The test was halted during the transition to full power test conditions due to a mechanical failure of the GTSB. Alzeta engineers believed that the failure was caused by flashback (the flame-front moved backwards toward the GTSB surface and rapidly burned the air-fuel mixture inside of the

fuel injector). All tests performed up to the full engine operating condition demonstrated NOX below 5 ppm (adjusted to 15% oxygen) and CO less than 10 ppm. Unburned hydrocarbon emissions were undetectable under most conditions. All tests were accomplished using only one segment of the two-segment GTSB. The tests using various fuel splits between segments could not be accomplished after the failure of the test GTSB. Since only one day of testing was available at the Honeywell test facility, retesting could not be accomplished.

**Conclusions:**

Alzeta's segmented GTSB operated as planned at atmospheric pressure conditions. Alzeta's GTSB is capable of producing sub-5 ppm NOX, sub-10 ppm CO, and near zero unburned hydrocarbons at partial load operating conditions of the Honeywell Parallon 75 micro-turbine. Collected temperature data demonstrate that GTSB combustion performance is consistent with Honeywell's combustor design and can be adapted without changing the materials of construction. Demonstration of the segmented GTSB at full engine load conditions was not accomplished due to component failure.

Subsequent to the completion of this project, Honeywell decided to exit the micro-turbine business. This does not diminish the value of the research conducted during this project. Even though the important technical objective of testing a segmented GTSB at engine pressures is yet to be achieved, this EISG funded project has advanced segmented GTSB technology.

**Benefits to California:**

Once commercialized, the GTSB may allow low emissions turbine generators to be sited in California at a reasonable cost. Actual engine emissions with the GTSB must meet emission control standards in effect at the time of commercialization. The segmented GTSB appears to provide low emissions over a broader load range than currently available technology. This increases design and operational flexibility for turbine engine manufacturers. Distributed power generation has the potential to reduce peak demand on California's power grid and provide reliable backup power in the face of potential power shortages.

**Recommendations:**

Successful demonstration of the segmented GTSB at points traversing the startup fuel schedule and over the entire load range at atmospheric conditions could lead to an engine ready design and testing in a micro-turbine or full size turbine. Once the GTSB is installed in an engine, the engine start schedule and control logic will have to be developed to provide low emissions over the load range. Extended demonstration in a test or field engine will provide critical operating data for the commercial GTSB micro-turbine product. Finally, GTSB durability and flashback prevention should be objectives of subsequent research and development. The California Energy Commission awarded Alzeta another development program for this burner concept in March of 2001 and has recently announced its intention to expand this line of research under the Environmentally Preferred Advanced Generation subject area of the PIER Program. The Program Administration endorses these actions.

**Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.



## Process for Converting Sewage Sludge& Municipal Solid Wastes to Clean Fuels

**EISG Grant Number:** 99-04

**PIER Area:** Renewables

**Principal Investigator:** Radon Tolman (760) 967-8494

**Organization:** Environmental Energy Systems, Inc.

**Grant Amount:** \$75,000

**Status:** Completed

### Project Description:

Most new power plants being installed in California are Gas Turbine Combined Cycle (GTCC) plants that burn increasingly expensive natural gas and fuel oil to produce electricity at up to 60% efficiency. These plants can be installed in less than half the time and at less than half the cost of new coal-fired plants and Integrated Gasification Combined Cycle (IGCC) plants that use cheap dirty fuels, but are less than 42% efficient. A new system is needed to adapt the new plants to cheaper fuels, while maintaining their efficiency and environmental performance.

This project researched the feasibility of a supercritical water gasification (SCWG) process to convert compost made from municipal solid wastes and sewage sludge to clean energetic gases. The expectation is to reduce the fuel costs of GTCC plants and to improve both efficiency and environmental performance of existing steam power plants.

### Proposed Outcomes:

1. Determine the feasibility of using SCWG to gasify composted municipal solid waste/sludge, consisting of at least 23 wt% solids, with a minimum 96% conversion of carbon to gas.
2. Verify through visual inspection that no significant erosion, corrosion and deposition occurred inside the bench-scale SCWG system.
3. Assess the feasibility of recycling resulting liquids for “zero effluent” design.
4. Update and validate simplified thermodynamic computer simulation and a life cycle cost models that can be used to predict system performance with various fuels.

### Actual Outcomes:

1. Use of SCWG to gasify composted municipal solid waste/sludge is feasible by a wide margin:
  - We produced a pumpable slurry mixture containing 40 wt% solids, exceeding the target goal by 74%.
  - The bench-scale system converted over 98% of the carbon in the slurry to energetic gases and steam, including clean pressurized methane, hydrocarbons and carbon oxides in less than one minute, which is twice as fast as the target time.
2. No noticeable erosion, corrosion or deposition was observed in the test equipment.
3. Total suspended solids in the liquid effluent was less than 10%, supporting the feasibility of recycling liquids for slurry preparation after filtering to provide a “zero effluent” design. No toxic materials were produced that would limit disposal of the residue in a landfill.
4. A thermodynamic computer simulation model and a life cycle cost model were prepared, however, there was insufficient funding in the current project to validate the models over a range of inputs, including the test data. Equilibrium compositions were assumed to be sufficiently close to expected commercial operations to provide preliminary predictions of system performance. Results of the computer simulations included:

- Projected 62% thermal efficiency to electric power for the entire proposed hybrid plant. Projected efficiency for retrofit in an existing steam power plant is 52%.
- Projected capital costs of \$1,100/kWh for a new hybrid plant, with projected cost of baseload power generation at \$100/MWh.
- Projected capital costs of \$500/kWh for retrofit to an existing GTCC plant, with projected cost of baseload power generation at \$50/MWh.
- Retrofits for repowering existing Steam plants are competitive with GTCC plants burning natural gas costing \$3.00 or more /million Btu.

### Conclusions:

1. The test results support the continued investigation of composted municipal waste as an economical fuel source for GTCC and existing steam power plants.
2. We demonstrated that compost made from municipal solid wastes and sewage sludge can be made into a slurry with 40 wt% solids, which significantly increases the range of applications, including the production of valuable byproducts, such as hydrogen. This mixture tended to clog in the 1/4" preheater tube which was completely alleviated by changing to 3/8" tubing. This problem is not expected in larger tubes.
3. The project successfully demonstrated that the compost slurry can be used in a SCWG process to produce energetic gases and steam, including approximately 35% gaseous hydrocarbons and hydrogen, the largest fraction being methane. The remaining 65% of the carbon in the feed was converted mainly to CO<sub>2</sub> and a small amount of CO. The CO<sub>2</sub> can be separated for reduced emissions. It is unknown what effect compost grinding had on residence time for gasification. It is also unknown what impact scaling up the reactor tubes will have on the SCWG process.
5. Sufficient yield data was collected to determine gas composition, perform a carbon balance and perform a preliminary evaluation of recycling liquids after filtering for slurry preparation. While no corrosion, erosion or deposition was observed after running the tests, the tests conducted were not designed to accurately assess those effects over long term testing.
6. Environmentally, based on residence time and projected full scale HRSG tubes, a standard module of 100 HRSG tubes per 25 MW turbine can consume an estimated 170 tons of composted municipal solid waste per day, reducing it to approximately 34 tons of inorganic material.
7. The results of the computer simulation models are encouraging in terms of supporting an economic case for commercialization however, the models still include many assumptions that remain to be validated.

### Benefits to California:

This project contributed to the Public Interest Energy Research (PIER) program objective of improving energy cost of California electricity through the use of inexpensive biomass fuels. The project also supports the PIER objective of improving the environmental risk by diverting waste streams away from landfills.

Successful commercialization of SCWG technologies could promote business opportunities in several industries, including process development, waste disposal, electrical generation, pollution control and transportation fuels.



**Recommendations:**

The next research step is to scale up the critical elements of the SCWG system to eliminate the problems associated with the bench-scale system used in the current project and to conduct a series of tests that more accurately represent anticipated operational conditions. General Atomics in San Diego is currently constructing a scaled up SCWG test rig with full-scale HRSG reactor tubes that would be suitable for answering the outstanding technical questions. The following technical questions need to be answered:

1. Test a full range of slurry concentrations in full size reactor tubes to identify the associated impact on steam and fuel gas production.
2. Identify the optimum level of grinding required (if any) for trouble free gasification in full size reactor tubes.
3. Confirm slurry distribution in a 10-tube inlet manifold for scale-up to a commercial plant.
4. Confirm that the energy balance for SCWG is the same using full size reactor tubes.
5. Evaluate the longer-term potential for corrosion, erosion or deposition.
6. Test condensate for yield and quality and cleaning methods for recycle to slurry preparation.
7. Test ash for beneficial use or land filling.
8. Test mild operating conditions for byproduct yields and quality, including liquid hydrocarbons and carbon.
9. Refine computer models and economic feasibility analyses for retrofit to existing gas turbines and boilers.
10. Collect and test fuel gases for combustibility in existing gas turbines, fuel cells and boilers.

**Project Status:**

- 100% Completed.
- Completed on Schedule.
- Completed within Budget.
- Final Report Completed.
- Feasibility Analysis Report Completed.